# DOCUMENT RESUME

ED 469 106 SE 066 852

| | |
|---|---|
| AUTHOR | Smith, P. Sean |
| TITLE | Astronomy: Project Earth Science. |
| INSTITUTION | National Science Teachers Association, Arlington, VA. |
| SPONS AGENCY | BP America, Cleveland, OH. |
| ISBN | ISBN-0-87355-108-7 |
| PUB DATE | 2001-00-00 |
| NOTE | 149p.; A Project of Horizon Research, Inc. |
| AVAILABLE FROM | NSTA Press, 1840 Wilson Blvd., Arlington, VA 22201-3000 ($25.95). Web site: http://www.nsta.org. |
| PUB TYPE | Books (010) -- Guides - Classroom - Teacher (052) |
| EDRS PRICE | EDRS Price MF01 Plus Postage. PC Not Available from EDRS |
| DESCRIPTORS | Academic Standards; *Astronomy; Concept Formation; Earth Science; Elementary Secondary Education; Hands on Science; Misconceptions; National Standards; *Science Activities; Science Instruction; *Space Sciences |
| IDENTIFIERS | National Science Education Standards |

ABSTRACT

This book presents classroom activities and reading materials. The activities use a hands-on approach and address the standards. Each features both a student section and a teacher guide. Eleven activities include: (1) "It's Only a Paper Moon"; (2) "Time Traveler"; (3) "Solar System Scale"; (4) "Hello Out There!"; (5) "How Far to the Star?"; (6) "Solar System Soup: The Formation of the Solar System"; (7) "The Goldilocks Effect or 'This Planet Is Just Right!'"; (8) "The Greenhouse Effect"; (9) "Creature Feature"; (10) "Reason for the Seasons"; and (11) "Ping-Pong Phases." Readings include: (1) "Angular Diameter"; (2) "What Is a Light Year?"; (3) "Hubble Space Telescope"; (4) "Scale Measurements"; (5) "Scouting Earth/Moon"; (6) "The Parallax Effect"; (7) "Understanding the Earth as a System"; (8) "After the Warming"; (9) "Atmosphere, Oceans, Cryosphere, and Hydrologic Cycle"; (10) "The Greenhouse Effect"; (11) "Interaction of Human Activities with the Natural Environment"; (12) "Reason for the Seasons"; (13) "Phases of the Moon"; and (14) "Understanding the Moon Illusion." (YDS)

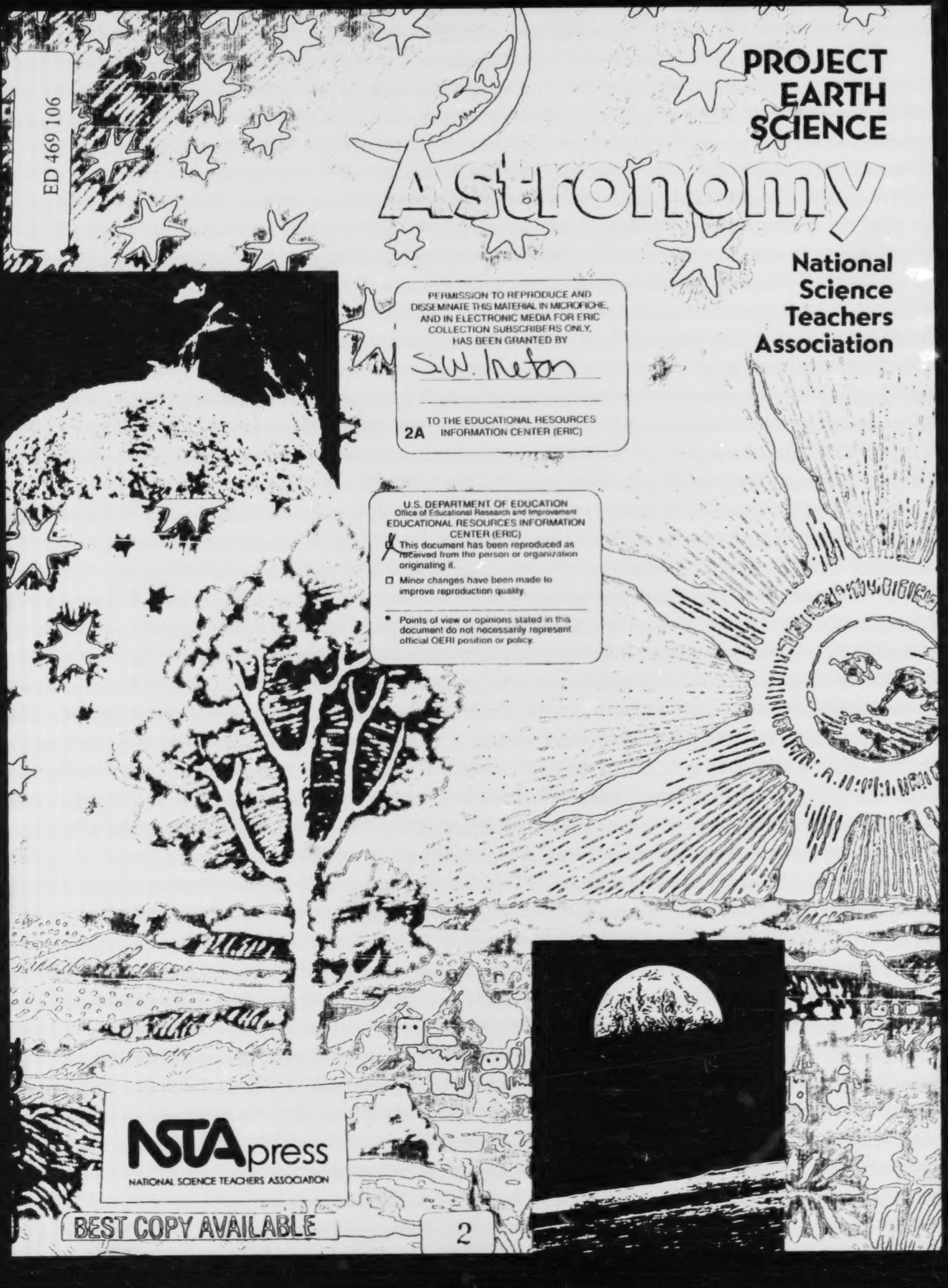
Reproductions supplied by EDRS are the best that can be made
from the original document.

ED 469 106

# PROJECT EARTH SCIENCE

# Astronomy

National Science Teachers Association



PERMISSION TO REPRODUCE AND DISSEMINATE THIS MATERIAL IN MICROFICHE, AND IN ELECTRONIC MEDIA FOR ERIC COLLECTION SUBSCRIBERS ONLY, HAS BEEN GRANTED BY

S.W. Ireton

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

2A

U.S. DEPARTMENT OF EDUCATION
Office of Educational Research and Improvement
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

☑ This document has been reproduced as received from the person or organization originating it.

☐ Minor changes have been made to improve reproduction quality.

- Points of view or opinions stated in this document do not necessarily represent official OERI position or policy.

NSTApress
NATIONAL SCIENCE TEACHERS ASSOCIATION

BEST COPY AVAILABLE

# Project Earth Science: Astronomy

NSTApress
NATIONAL SCIENCE TEACHERS ASSOCIATION

Shirley Watt Ireton, Director
Beth Daniels, Managing Editor
Judy Cusick, Associate Editor
Carol Duval, Associate Editor

**Art and Design**
Linda Olliver, Director
**NSTA Web**
Tim Weber, Webmaster
**Periodicals Publishing**
Shelley Carey, Director
**Printing and Production**
Catherine Lorrain-Hale, Director
**Publications Operations**
Erin Miller, Manager
***sci*LINKS**
Tyson Brown, Manager

**National Science Teachers Association**
Gerald F. Wheeler, Executive Director
David Beacom, Publisher

NSTA Press, NSTA Journals, and the NSTA website deliver high-quality resources for science educators.

---

*Project Earth Science: Astronomy*
NSTA Stock Number: PB090X
ISBN 0-87355-108-7
Library of Congress Card Number: 92-60246
Printed in the USA by Automated Graphic Systems.
Printed on recycled paper.
Design by Marty Ittner of Auras Design, Inc.
Illustrations by the author and by Max-Karl Winkler .

NSTA National Science Teachers Association

Copyright © 1996, 1998, 2001 by the National Science Teachers Association.
The mission of the National Science Teachers Association is to promote excellence and innovation in science teaching and learning for all.

Permission is granted in advance for reproduction for purpose of classroom or workshop instruction. To request permission for other uses, send specific requests to:

NSTA Press
1840 Wilson Boulevard
Arlington, Virginia 22201-3000
www.nsta.org

# Project Earth Science: Astronomy

## by P. Sean Smith

SCiLINKS.
THE WORLD'S A CLICK AWAY

Featuring *sci*LINKS®—a new way of connecting text and the Internet. Up-to-the-minute online content, classroom ideas, and other materials are just a click away. Go to page 151 to learn more about this educational resource.

NSTApress
NATIONAL SCIENCE TEACHERS ASSOCIATION
Arlington, Virginia

**A Project of Horizon Research, Inc.**
**Material for middle school teachers in Earth science**
**This project was funded by BP America, Inc.**

BEST COPY AVAILABLE

# Project Earth Science: Astronomy

## Table of Contents

Acknowledgments 7

Overview 9

Introduction 9

Getting Ready for Classroom Instruction 9

*Project Earth Science: Astronomy* and the *National Science Education Standards* 13

## Activities

**Activity 1** It's Only a Paper Moon 15

**Activity 2** Time Traveler 23

**Activity 3** Solar System Scale 29

**Activity 4** Hello Out There! 37

**Activity 5** How Far to the Star? 45

**Activity 6** Solar System Soup: The Formation of the Solar System 53

**Activity 7** The Goldilocks Effect or "This Planet Is Just Right!" 59

**Activity 8** The Greenhouse Effect 67

**Activity 9** Creature Feature 75

**Activity 10** Reason for the Seasons 83

**Activity 11** Ping-Pong Phases 91

## Readings

Angular Diameters....................103 **Reading 1**

What Is a Light Year?....................106 **Reading 2**

Hubble Space Telescope....................108 **Reading 3**

Scale Measurements....................109 **Reading 4**

Scouting Earth/Moon....................111 **Reading 5**

The Parallax Effect....................112 **Reading 6**

Understanding the Earth as a System....................114 **Reading 7**

After the Warming....................116 **Reading 8**

Atmosphere, Oceans, Cryosphere, and Hydrologic Cycle....................122 **Reading 9**

The Greenhouse Effect....................124 **Reading 10**

Interaction of Human Activities with the Natural Environment....................127 **Reading 11**

Reason for the Seasons....................129 **Reading 12**

Phases of the Moon....................132 **Reading 13**

Understanding the Moon Illusion....................134 **Reading 14**

## Appendices

Appendix A: Master Materials List.................... 138

Appendix B: Resource Guide....................140

Appendix C: Standards Organizational Matrix....................148

"Moon," by Myra Cohn Livingston, reprinted from *Space Songs* (New York: Holiday House Books, © 1988), by permission of Marian Reiner for the author.

"A Distant Sun," by Lydia Ferguson, reprinted from *New Voices in American Poetry* (New York: Vantage Press, 1978), by permission of the author.

"The Planets," by Myra Cohn Livingston, reprinted from *Sky Songs* (New York: Holiday House Books, © 1984), by permission of Marian Reiner for the author.

"Messages," by Myra Cohn Livingston, reprinted from *Space Songs* (New York: Holiday House Books, © 1988), by permission of Marian Reiner for the author.

"Jewels," by Myra Cohn Livingston, reprinted from *Space Songs* (New York: Holiday House Books, © 1988), by permission of Marian Reiner for the author.

"Stars," by Sara Teasdale, reprinted from *The Collected Poems of Sara Teasdale* (New York: Macmillan Publishing Company, © 1920, renewed 1948 by Mamie T. Wheless), by permission of the publisher.

Quotes from astronauts John Caffrey and Jeff Hoffman reprinted courtesy of NASA.

"Seasons," by Evelyn Nitso, reprinted from *New Voices in American Poetry* (New York: Vantage Press, 1978), by permission of the author.

"Winter Moon," by Langston Hughes, reprinted from *Selected Poems of Langston Hughes* (New York: Random House, 1974), by permission of the publisher.

**About the Cover Photographs** (Reprinted courtesy of NASA)

Front Cover

The photo of Earth rising was taken by the Apollo 10 astronauts, approximately 160,000 kilometers from Earth. Europe, Asia, and parts of Africa are visible through scattered cloud cover.

The photo of the Sun, taken in 1973 from Skylab 4, shows one of the most spectacular solar flares ever recorded, spanning more than 588,000 kilometers across the solar surface.

Back Cover

This color-enhanced photo of the Sun was also taken in 1973 from Skylab. The Sun's corona stretches far beyond the denser, inner corona seen in X-ray and ultraviolet light images, and beyond the limits of what we normally see in the dark sky of a total solar eclipse.

8

## Acknowledgments

Numerous people have contributed to the development of *Project Earth Science: Astronomy*. The volume began as a collection of activities and readings for Project Earth Science, a teacher enhancement project funded by the National Science Foundation. Project Earth Science was designed to provide in-service education for middle school Earth science teachers in North Carolina. Nine two-person leadership teams received extensive training in conducting in-service workshops on selected topics in astronomy, geology, meteorology, and oceanography. They in turn conducted in-service education programs for teachers throughout the state of North Carolina. Principal investigators for this project were Iris R. Weiss, president of Horizon Research, Inc.; Diana Montgomery, research associate at Horizon Research, Inc.; Paul B. Hounshell, professor of education, University of North Carolina-Chapel Hill; and Paul Fullagar, professor of geology, University of North Carolina-Chapel Hill. Brent Ford, president of Novostar Designs, Inc. and a consultant to Horizon Research, also played a major role in this project both in development of activities and organization of workshops.

The activities and readings have undergone many revisions as a result of the comments and suggestions provided primarily by the Project Earth Science leaders and also by workshop participants, project consultants, and project staff. The Project Earth Science leaders made this book possible through their creativity and unceasing attention to the needs of students and classroom teachers. The leaders are: Kevin Barnard, Winston-Salem/Forsyth County Schools; Kathy Bobay, Charlotte-Mecklenburg Schools; Pam Bookout, Guilford County Schools; Betty Dean, Guilford County Schools; Lynanne (Missy) Gabriel, Charlotte-Mecklenburg Schools; Flo Gullickson, Guilford County Schools; Michele Heath, Chapel Hill/Carrboro Schools; Cameron Holbrook, Winston-Salem/Forsyth County Schools; Linda Hollingsworth, Randolph County Schools; Geoff Holt, formerly of Wake County Schools; Kim Kelly, Chapel Hill/Carrboro Schools; Laura Kolb, Wake County Schools; Karen Kozel, Durham County Schools; Kim Taylor, Durham County Schools; Dana White, Wake County Schools; Tammy Williams, Guilford County Schools; and Lowell Zeigler, Wake County Schools. Special thanks to Geoff Holt for his contributions to "How Far to the Star?" and "Ping-Pong Phases," to Kevin Barnard for his contributions to "Solar System Soup," and to Missy Gabriel for her contributions to "Creature Feature."

BEST COPY AVAILABLE

The manuscript was reviewed for scientific accuracy by Wayne Christiansen, professor of astronomy at the University of North Carolina-Chapel Hill. Dr. Christiansen contributed valuable suggestions on all the activities and the original idea for some of them.

Shirley Brown, a teacher with the Columbus City Schools in Ohio and a participant in the Program for Leadership in Earth Systems Education (PLESE) at Ohio State University, contributed many of the items in the Appendix as well as the poems at the beginning of each activity. She also provided many of the ideas in "Suggestions for Interdisciplinary Reading and Study" in the activities.

During the original publication process excellent reviewers provided their comments and suggestions to NSTA: Darrel Hoff, director of Project ESTEEM (Earth Science Teachers Exploring Exemplary Materials) and professor emeritus at the University of Northern Iowa; Mary Kay Hemenway, senior astronomy lecturer at the University of Texas-Austin and secretary to the Board of the Astronomical Society of the Pacific (Dr. Hemenway also reviewed the 2001 revision); Katherine Becker, science education specialist at Creighton University; and Mark Brockmeyer, science teacher at City High School in Iowa City.

*Project Earth Science: Astronomy* was produced by NSTA publications, Shirley Watt Ireton, managing editor; Christine Marie Pearce, assistant editor; Andrew Saindon, assistant editor, Gregg Sekscienski, production editor; Anne Marie Calmes, editorial assistant; and Daniel T. Shannon, editorial assistant. Christine Pearce was the original NSTA editor for *Project Earth Science: Astronomy;* Judy Cusick was the project editor of the 2001 revision.

Special thanks go to BP America, Inc., for providing the funds to make this book possible.

## Overview

*Project Earth Science: Astronomy* is the first in a four-volume series of Earth science books. The remaining three are *Meteorology*, *Physical Oceanography*, and *Geology*. Each volume contains a collection of hands-on activities developed for the middle/junior high school level and a series of background readings pertaining to the topic area.

Project Earth Science was funded by the National Science Foundation in 1989. Originally conceived as a program in leadership development, the purpose of the project was to prepare middle school teachers to lead workshops on topics in Earth science. These workshops were designed to help teachers convey the content of Earth science through the use of hands-on activities. With the help of content-area experts, concept outlines were developed for each topic area, and then activities were chosen which illustrated the concepts. Some activities were drawn from existing sources, and many others were developed by Project Earth Science leaders and staff.

Over the course of the two-year project, the activities were field tested both in workshops and in classrooms and were extensively revised. After each revision, the activities were reviewed by content experts for accuracy. Finally, all activities were organized in a standard format. During the publication process, the book underwent another extensive review and revision.

The grand theme of the Project Earth Science materials is the uniqueness of Earth among all the planets in the Solar System. Concepts and activities were chosen that elaborate on this theme. The *Astronomy* volume focuses on planetary astronomy. The object of this volume is to give students a sense of viewing Earth from some point beyond the Solar System. By placing Earth in the context of the Solar System and viewing it as "just another planet," it is hoped that students will begin to grasp the unique aspects of the planet. Chief among these aspects is that Earth is the only planet in the Solar System capable of sustaining life.

## Introduction

Everyone has wondered if there is life elsewhere in the Universe. Could those distant, tiny points of light seen in the night sky have orbiting planets that might also have intelligent life forms? What is it about planet Earth that makes life possible? Do any other

11

planets in our Solar System have the same or similar conditions? Do they have water or oxygen? Where are the other planets located in relation to Earth and the Sun?

In the last 50 years, space exploration has advanced our knowledge of the neighboring planets that share our Sun. The Pioneer and Voyager missions studied Jupiter extensively. Today the NASA spacecraft Galileo continues to explore Jupiter with more advanced instruments. The Viking mission landed a spacecraft on Mars and retrieved and analyzed its soil for traces of life. The Voyager missions, launched in 1977 and still continuing, have given us revealing photographs and detailed information on the giant planets of Jupiter, Saturn, Uranus, and Neptune. For the first time we can compare their geological and meteorological conditions with those of Earth. As scientists accumulate this new data, it also reveals how life, as we know it, is unique to Earth.

SCILINKS.
THE WORLD'S A CLICK AWAY

**Topic: space probes**
**Go to: *www.scilinks.org***
**Code: PESA10**

The space program has given us a snapshot of our own blue and white planet as photographed by journeying spaceships. Imagine what you would see if you could look at Earth from a point above the entire Solar System. What would Earth look like, and how big would it be compared to the other planets? Does it spin and revolve like the others? Do the other planets have a Moon like Earth's? Is the Solar System crowded?

To answer these questions, we must first know where Earth is in relation to all the other planets. The Sun is at the center of the Solar System with fast-orbiting Mercury in the first planet position. Venus is next, followed by Earth and Mars as you move out from the Sun. Moving still farther away are the giant planets Jupiter, Saturn, Uranus, and Neptune. The Solar System's smallest and most distant planet is Pluto, the only planet not yet explored by a space mission. Its unusual characteristics cause some astronomers to argue whether it should even be called a planet. In many ways, it is more like a small moon or large asteroid.

Only when Earth is placed in the context of the Solar System and considered as just another planet do its unique features come to light. NASA has a large program called Destination Earth: NASA's Earth Science Enterprise (*www.earth.nasa.gov*), whose goal is to study Earth as one global system. This is the perspective NASA has taken in studying every other planet. Now it is turning its attention back to our planet instead of out to the rest of the Universe. Some of Earth's unique aspects have already been discovered using this approach. As NASA recently wrote: "If Earth were much smaller, it could not retain an atmosphere. If it were much closer to or much further from the Sun, the oceans would boil or freeze. If its orbit and axis of rotation did not fluctuate, the cyclical variations in climate that have spurred evolution would not exist."

## Getting Ready for Classroom Instruction

The activities in this volume are organized under three broad concepts. First, students investigate techniques that are used to measure distances and sizes of the magnitude found in the Solar System. Using the information gained from these methods, students then place Earth in the Solar System in relation to the rest of the planets. Second, students perform activities that stress the uniqueness of Earth. This section focuses on comparisons of Earth to other planets, particularly Venus and Mars. In the third section of the book, students are confronted with two areas of planetary astronomy about which many people have misconceptions: the reason for the phases of the Moon and the explanation of Earth's seasons.

We suggest organizing Project Earth Science activities around key concepts. To facilitate this approach, the conceptual outline for *Astronomy* is presented below, with the numbers of the activities that pertain to each concept.

1. While Earth's position relative to the Sun and other planets is always changing, its *distance* from the Sun is almost constant. To understand many features of Earth which make it unique and habitable, we need to know where it is in relation to the Sun and other planets. Several tools are available to learn where Earth is in the Solar System. (Activities 1, 2, 3, 4, and 5.)
2. Earth's position in the Solar System is responsible for its unique properties. Among these properties is the fact that Earth is the only planet in the Solar System that sustains life. (Activities 6, 7, 8, and 9.)
3. Many misconceptions exist about Earth and its characteristics. Looking at Earth as "just another planet" can help correct these misconceptions. (Activities 10 and 11.)

## Organization

The activities in this volume are designed to be hands-on. In collecting and developing these activities, effort was made to use materials that are either readily available in the classroom or inexpensive to purchase.

Each activity has a student section and a teacher guide. The student section has background information which briefly explains the concepts behind the activity in non-technical terms. Following this is the procedure for the activity and a set of questions to guide the students as they draw conclusions.

The teacher versions of the activities, entitled "Teacher's Guide to Activity," contain a more detailed version of the background information given to the students and a summary of the important points that students should understand after completing the activity. You'll find the approximate time to allow for each activity in the section entitled "Time Management." The "Preparation" section describes the set-up for the activity and gives sources of materials. "Suggestions for Further Study" gives ideas for challenging students to extend their study of the topic. Use these ideas within the class period allotted for the activity if time and enthusiasm allow. "Suggestions for Interdisciplinary Reading and Study" includes ideas for relating the concepts in the activity to other science topics and to other disciplines such as language arts and social studies. The final section of the teacher's guide provides answers to the questions in the student section of the activity.

Each activity begins with a poem or quote whose imagery has an astronomical theme. The nighttime skies have been a fascination and an inspiration to the scientific and artistic intellect alike from time immemorial. You may want to copy these poems to accompany the activities—maybe to remind students of the interwoven nature of arts and sciences or to use elsewhere in the curriculum.

The activities are followed by a section of readings for the teacher. One or more of these readings are referred to in the guide to each activity. The readings provide both background information on the concepts underlying the activities as well as supplementary information to enhance classroom discussions.

Project Earth Science began as a workshop method to provide assistance to teachers on Earth science content and instructional techniques. To use this volume for teacher workshops, we've included a master materials list on page 138.

A guide to astronomy resources for students and teachers follows on page 140. Though not exhaustive, the guide should give teachers the means to explore this fascinating subject.

## *Project Earth Science: Astronomy* and the *National Science Education Standards*

Effective science teaching within the middle-level age cluster integrates the two broadest groupings of scientific activity identified by the *National Science Education Standards:* (1) developing skills and abilities necessary to perform scientific inquiry, and (2) developing an understanding of the implications and applications of scientific inquiry. Within the context of these two broad groupings, the Standards identify specific categories of classroom activity that will encourage and enable students to integrate skills and abilities with understanding.

To facilitate this integration, a Standards organizational matrix for *Project Earth Science: Astronomy* appears on pages 148-149. The categories listed along the X-axis of the matrix, also listed below, correspond to the categories of performing and understanding scientific activity identified as appropriate by the Standards.

**Subject Matter and Content.** Specifies the topic covered by an activity.

**Scientific Inquiry.** Identifies the "process of science" (i.e., scientific reasoning, critical thinking, conducting investigations, formulating hypotheses) employed by an activity.

**Unifying Concepts and Processes.** Links an activity's specific subject topic with "the big picture" of scientific ideas (i.e., how data collection techniques inform interpretation and analysis).

**Technology.** Establishes a connection between the natural and designed worlds.

**Personal/Social Perspectives.** Locates the specific astronomy topic covered by an activity within a framework that relates directly to students' lives.

**Historical Context.** Portrays scientific endeavor as an ongoing human enterprise by linking an activity's topic with the evolution of its underlying principle.

## Moon

Moon remembers.

Marooned in shadowed nights,

white powder plastered
on her pockmarked face,
scarred with craters,
filled with waterless seas,

she thinks back
to the Eagle,
to the flight
of men from Earth,
of rocks sent back in space,
and one
faint
footprint
in the Sea of Tranquility.

*Myra Cohn Livingston*

BEST COPY AVAILABLE

# It's Only a Paper Moon

## Background

It is very difficult to measure the diameter of objects in the Solar System. Unlike objects on Earth, it is not possible to hold a meter stick up to the planets and measure them. There are, however, other kinds of measurements called **indirect measurements** that do not require going to the object. These methods allow us to measure objects millions of kilometers away without ever leaving Earth. One type of indirect measurement is known as **angular diameter**.

The easiest way to understand angular diameter is to look at an example. The angular diameter of the Moon is $^1/_2$°. What does this mean? If it were possible to stretch two strings from the same point on Earth to opposite sides of the Moon, the angle between the strings would be 1/2° (see figure 1).

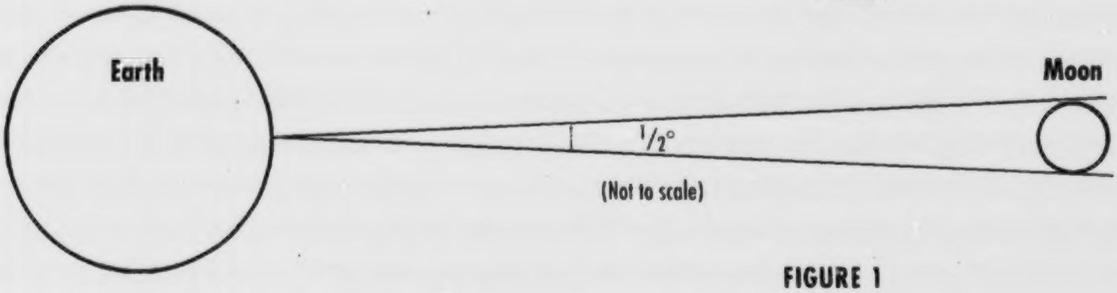


FIGURE 1

Angular diameters have an interesting property, which you will investigate in this activity, that makes them useful in determining the true size of objects in the Solar System. You will be making a "cross staff," which was used by ancient peoples for navigation. Today, astronauts use a cross staff during space walks. They essentially have a cross piece built into their space suits so that they can judge their distance from the spacecraft.

## Procedure

1. Using scissors, cut a notch and hole in the index card as shown in figure 2.
2. Insert the metric ruler through the index card. On the wall attach the paper plate at eye level or higher.
3. Using the metric tape measure, make sure that your eye is

### Objective

The objective of this activity is to learn how angular diameters can be used to measure the true diameter of the Moon.

### Materials

For each group of students:

- ◊ paper plate
- ◊ metric ruler
- ◊ metric tape measure
- ◊ index card
- ◊ scissors

SCILINKS. THE WORLD'S A CLICK AWAY

Topic: speed of light
Go to: *www.scilinks.org*
Code: PESA15

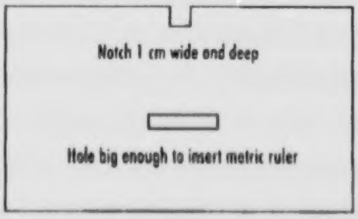


FIGURE 2

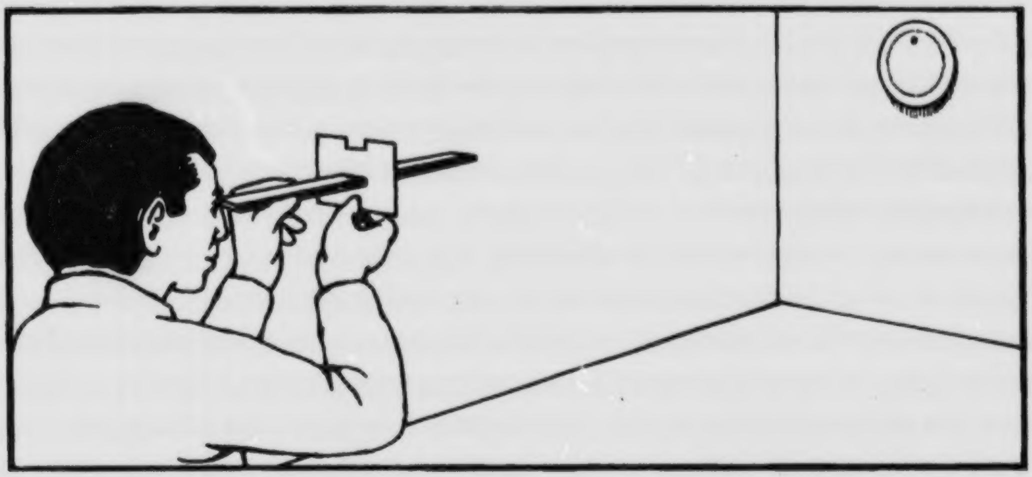


**FIGURE 3**

exactly 4 m from the plate. Then, holding the low numbered end of the metric ruler up to your eye, point it at the paper plate and sight through the notch along the ruler at the plate with one eye, as shown in figure 3.

4. Slide the index card along the ruler until the paper plate just fits inside the notch. (This is easier to do if you focus on the notch instead of the plate.) Now the notch and the plate have the same angular diameter.
5. Read the distance to the index card and add one centimeter to this measurement to account for the fact that the ruler was not exactly against your eye. Record this in the Data Table on the next page.
6. Repeat step 5 three more times, recording each measurement in the Data Table. Then take the average of the four measurements and record this as well.
7. Using the equation below, calculate the diameter of the plate and record it. This is possible because even though the notch and plate are different sizes, the index card was moved to the point where the notch had the same angular diameter as the plate.

$$\frac{\text{Diameter of the plate}}{\text{Diameter of the notch}} = \frac{\text{distance to the plate}}{\text{avg. distance to card}}$$

$$\text{Diameter of the plate} = \frac{400\text{ cm}}{\text{average distance to card}} \times 1\text{ cm}$$

8. Measure the true diameter of the plate and record it.

18

**DATA TABLE**

| | Distance to card (cm) | Avg. distance to card (cm) | Diameter of notch (cm) | Distance to plate (cm) | Calculated diameter of plate (cm) | Measured diameter of plate (cm) |
|---|---|---|---|---|---|---|
| **Trial 1** | | | | | | |
| **Trial 2** | | | | | | |
| **Trial 3** | | | | | | |
| **Trial 4** | | | | | | |

***Optional:*** Try this activity at night when the Moon is full and the sky is clear. Everything is done the same way except you will measure the diameter of the Moon instead of a plate. You will probably need a flashlight and someone to help you. You will also need to know the distance to the Moon: 38,440,100,000 cm.

## Questions and Conclusions

1. Compare the true diameter of the plate with the diameter you calculated. How do the two compare?
2. If the true and calculated diameters are not the same, what reasons could explain the difference?
3. Would this method of determining diameters be helpful in working with the planets in the Solar System? Why?
4. The full moon appears to be bigger when it is on the horizon than when it is high up in the sky. How could you use the method in this activity to determine whether this effect is real or an illusion?
5. Write a procedure for using the instrument in this activity to measure some tall object on the school grounds. You might choose a flagpole, a bus, or the school building. Be sure that your procedure is specific enough that anyone else reading it could do the measurement themselves.

# It's Only a Paper Moon

## Materials

For each group of students:

- paper plate
- metric ruler
- metric tape measure
- index card
- scissors

## Vocabulary

**Indirect measurement**: A measurement made by other than direct means. Physical proximity to the object or distance is not necessary. Examples of indirect measurement include angular diameter and parallax.

**Angular diameter**: The measure of an object's diameter in degrees of an arc rather than in linear measurement units. This is a type of indirect measurement. Angular diameters are used to calculate diameters of objects in the Solar System.

**Similar triangles**: Two triangles that have equal angles but sides of different lengths.

## What Is Happening?

Objects in the Solar System are extremely difficult to measure, primarily because they are so far away. There are, however, indirect ways of measuring these objects—for example, measuring angular diameters. An angular diameter is simply a diameter measured in degrees of an arc rather than centimeters or kilometers. The angular diameter of the Moon is 1/2°, as shown in figure 4.

Angular diameters have several interesting properties. The magnitude of an angular diameter depends on where the object is located. The closer an object is to the observer, the larger its angular diameter. Also, two objects with different *true* diameters can have the same *angular* diameter. If you hold a pencil in front of one of your eyes, you can use it to just block your view of a telephone pole. When you do this, you are adjusting the position of the pencil so that it has the same angular diameter as the telephone pole.

When two objects have the same angular diameter, a principle known as similar triangles can be employed to determine the true diameter of one of the objects as long as the true diameter of the other object is known. In similar triangles, the corresponding angles in each are equal even though the corresponding sides may not be, as shown in figure 5. Although the corresponding sides are not equal, their ratios are. So as long as some measurements are known, others can be determined by setting up the appropriate ratios.

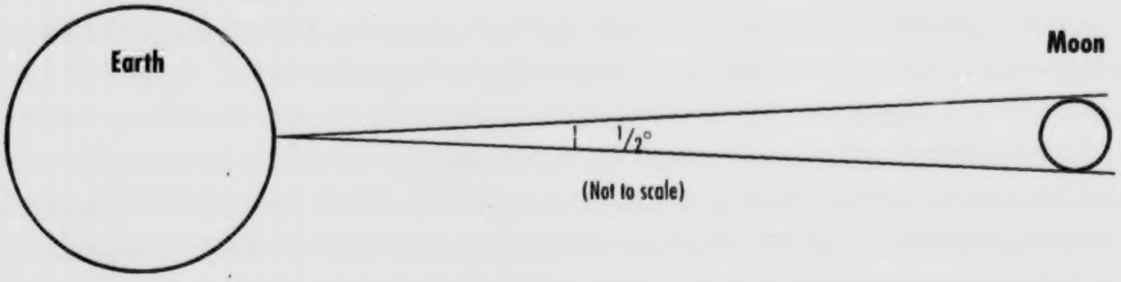


FIGURE 4

Figure 6 shows how the principle of similar triangles and angular diameters can be used to determine the true diameter of the Moon. The distance to the card, the distance to the Moon (the paper plate in this activity), and the diameter of the notch are all known. This means that the true diameter of the Moon can be calculated using the ratio:

$$\frac{\text{diameter of the Moon}}{\text{diameter of the notch}} = \frac{\text{distance to the Moon}}{\text{distance to the card}}$$

In this activity, students will learn how to use this method. For the activity to be more than an exercise in plugging numbers into an equation, it will be necessary to explain to the students the properties of angular diameters that make the equation possible, as described above. These properties are summarized in the next section.

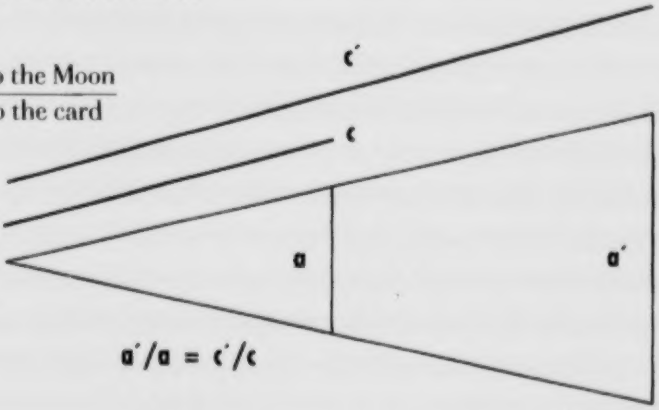


FIGURE 5

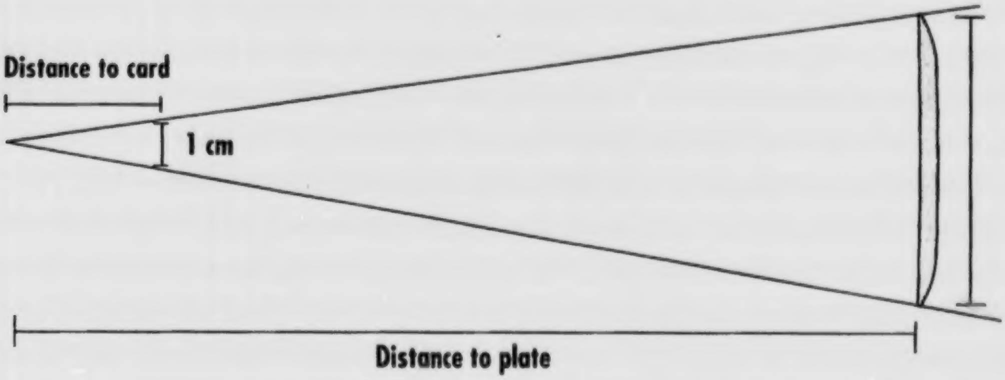


FIGURE 6

## Important Points for Students to Understand

◊ While an object's true diameter is constant, its angular diameter depends on the location of the object in relation to the viewer; i.e., the closer an object is, the larger its angular diameter.

◊ Two objects of different size can have the same angular diameter.

◊ When two objects of different size have the same angular diameter, the principle of similar triangles can be used to determine the size of one of the objects.

## Time Management

This activity will take one class period or less.

## Preparation

Have all the materials centrally located so that students can obtain them easily. Make sure that there is enough space in the room for all the students to work at once, either individually or in groups. It is helpful to mark in advance the spaces where groups of students can work.

For additional background information refer to Reading 1, "Angular Diameters" and Reading 14, "Understanding the Moon Illusion."

## Suggestions for Further Study

Encourage students to carry out the optional activity explained in the student section. In addition, they may want to try the present activity with other objects besides paper plates, or they may want to try measuring the diameter of the plate again while standing at a different distance.

Now that spacecraft have reached all the planets but Pluto, much more accurate planetary data is available. Students might find it interesting to research some of the findings from the recent space missions. For example, they could compare older Earth science or astronomy books with the recent information.

Have students measure the north/south axis of the Moon during the day. The Moon's third quarter is visible in the morning and its phases from first quarter to full moon are visible in the afternoon. There is a common misconception that the Moon is only visible at night. Students who seldom look will occasionally notice the Moon in the day and think it a fluke without contemplating why.

## Suggestions for Interdisciplinary Reading and Study

As a preparation for this activity or as an independent activity, students could write their own definitions of "close" and "far," giving examples of each. A class discussion of the definitions might emphasize for the students how different people can have very different ideas about the same words. This would also be a good opportunity to point out that effective communication in science (and in general) depends both on using well-defined terms and on all parties agreeing on the definitions.

## Answers to Questions for Students

1. Depends on students' data. In all likelihood, the two will be close but not the same. Either may be larger than the other, providing a good opportunity to explore sources of error in measurement.
2. Among the many sources of experimental error are: inaccurate measurement (of plate diameter, of index card distance or notch diameter, of distance to plate), not remaining stationary from measurement to measurement, and changing position of the metric ruler from measurement to measurement.
3. This method, if adapted for use with a telescope, works well for all the planets except Pluto. (Pluto is too far away and too small, even if you are using a telescope.)
4. Calculate the Moon's diameter at moonrise and at "moon noon." Compare the two. They should be the same.

   The reason the Moon appears bigger on the horizon is that we perceive the horizon to be farther away than the sky above us. So for the Moon to have the same angular diameter at two different distances (on the horizon and above us), our mind interprets the object farther away (on the horizon) as being larger than the one nearer (overhead) to us. (Refer to the Reading 14, "Understanding the Moon Illusion," for further explanation of this phenomenon.)
5. ***Note*:** Answers will vary. The important thing is that the procedure is feasible. If time and materials are available, encourage the students to try their own procedures. There could even be a class vote to determine the best procedure based on feasibility, clarity, and accuracy of results.

## A Distant Sun

A distant sun is like a dream,
so very far away,
through clouds of doubt and darkness
is very hard to see.

But, ah, we feel its beauty,
though filtered it may be,
rays of hope and promises
light up our shadowed ways.

As we watch it cross the sky,
through silhouettes of life,
we feel our distant dreamings
draw closer to our sight.

*Lydia Ferguson*

BEST COPY AVAILABLE

# Time Traveler

### Objective

The objective of this activity is to develop an understanding of the concept of a unit known as the "light year."

### Materials

For each group of students:

- ◊ watch with second hand or a stop watch
- ◊ metric tape measure (30 meters or more works best)
- ◊ calculator (helpful but not essential)

## Background

Distances in astronomy are often very difficult to comprehend because they are so large. For example, the distance from the star Sirius to Earth is 84,320 trillion km. This distance is too large for most people to imagine or understand. There are ways, however, to make such large numbers more manageable. For example, it is much easier to understand and work with 15 years than with 5,475 days, even though they both represent the same amount of time. A "year" is just a much larger unit than a "day." The same type of thing can be done with distances using a measurement known as a **light year**.

A light year (abbreviated "ly") is a measurement of distance even though it involves a time unit, the year. A light year is defined as the distance that light will travel in one year. The speed of light is 300,000 km/s. To calculate how far light travels in one year, first calculate how many seconds there are in a year:

60 s/min × 60 min/hr × 24 hr/d × 365 d/yr = 31,536,000 s/yr

So in one year, light will travel

31,536,000 s × 300,000 km/s
= 9,461 trillion (9,461,00,000,000,000) km

This is the same as traveling around the world 118 million times.

The light year can make distances easier to understand in the same way that a year makes a large number of days more understandable. Returning to our example above, the distance to the star Sirius from Earth is 84,320 trillion km. But this distance is only 9 ly, a much more manageable number.

The light year is also important because it tells us about the time lag involved in communicating over the large distances involved in astronomy. If we sent a television or radio signal (both of which travel at the speed of light) to Sirius, it would be nine years before it arrived there. In the same way, if Sirius were to stop shining right now, we would not find out about it for nine more years, when the last light the star produced finally reached Earth. How old would you be then?

## Procedure

1. Find a long distance that you can use either inside or outside the school. This could be a long hallway, the cafeteria, a

parking lot, or a football field. You won't need a distance longer than a football field.

2. Starting at one end of the space you have chosen, walk heel-to-toe for exactly one minute. Mark where you stop.
3. Using the tape measure, measure how far you walked to the nearest meter. Record this distance in the Data Table.
4. Repeat steps 2 and 3 three more times.
5. Calculate the average of the four measurements and record it in the Data Table.

**DATA TABLE**

| | **Distance walked** | **Average distance walked** |
|---|---|---|
| **Trial 1** | | |
| **Trial 2** | | |
| **Trial 3** | | |
| **Trial 4** | | |

6. The average you calculated is the distance you can walk heel-to-toe in one minute. We will call this distance a "student minute."

## Questions and Conclusions

1. Are all the student minutes the same? How are they similar?
2. How are student minutes similar to a light year? How are they dissimilar?
3. How many meters are in 3 student minutes?
4. How many of your student minutes are there in 5,000 m?
5. Listening to the radio one morning at 6:30, you hear that school has been cancelled because of damage done in some parts of town by a windstorm. You start to climb back in bed and sleep the day away, but then you remember that your best friend lives in a part of town which was heavily damaged and has no telephone or electricity. Your friend leaves for school every morning at 7:00 and lives 900 m away from you. The only way you can get the news to your friend is to go to your friend's house and deliver the message. If you are only allowed to walk heel-to-toe, can you make it to the house in time based on your own student minute? Explain.

# Time Traveler

## What Is Happening?

Distances in astronomy are extremely hard for adults to comprehend, let alone middle or high school students. The units typically used for large measurements on Earth (the kilometer or mile) are too small to be of much help when measuring the distance to stars or other galaxies. For this reason, a unit known as the light year was developed. A light year is defined as the distance that light can travel in one year. Traveling at 300,000 km/s, light travels almost 9,461 trillion km in one year.

The light year is a difficult unit for students to understand. The problem lies in the terminology. A time unit, the "year," is being used to measure distance. This is not at all unfamiliar to students, however. It is very common today to talk about distance in terms of time. Students often do not talk about how many miles it is to a friend's house but how many minutes or hours it takes to get there. A comparison of the time-distance to a friend's house when walking, bicycling, or riding in a car can be a useful illustration of the concept that the time-distance unit depends on the speed of the carrier. Since light is the fastest (and most constant) possible carrier, it is the most useful for establishing the scale of huge astronomical distances.

The light year has another important property that is discussed in more detail in Activity 4, "Hello Out There!" The distance in light years that an object is from Earth is the amount of time in years that light from this object would take to reach Earth. For example, if a star is 12 ly from Earth, light from the star takes 12 years to reach us. Likewise, any light from Earth takes 12 years to reach the star.

This activity is designed to help students understand the light year by creating for themselves a unit which is similar, one that uses time to measure distance. It is important that students understand the nature of the unit. Creating their own unit should aid in this understanding. An important distinction, however, needs to be made between the "student minute" and the light year. The student minute may vary depending on how fast the student walks. The light year does not vary. It is a constant because the speed of light is a constant.

### Materials

For each group of students:

- ◊ watch with second hand or a stop watch
- ◊ metric tape measure (30 meters or more works best)
- ◊ calculator (helpful but not essential)

### Vocabulary

**Light year**: A unit of measurement equal to the distance light travels in one year (9,461 trillion km or 9,461,000,000,000,000 km).

## Important Points for Students to Understand

◊ Distances in astronomy are too large to work with easily when expressed in units such as kilometers. Using a larger unit makes these numbers easier to manage.

◊ The "light year" is a measurement of distance even though it involves a time unit.

◊ It is very common to express distances in terms of time.

◊ Light has a finite speed. It takes time for light to travel over any distance.

## Time Management

Depending on the availability of watches and tape measures, this activity should take one class period or less.

## Preparation

You should determine in advance what area the students will use for this activity. If an outdoor site is to be used, be sure the conditions are such that the students can remain outside comfortably for an extended period of time.

Rather than having the students measure each time they walk, it may be possible to use a lined football field. Alternatively, the teacher may mark off the distance. This can be done simply with a tape measure and marking paint.

For additional background, see Reading 2, "What is a Light Year?" and Reading 3, "Hubble Space Telescope."

## Suggestions for Further Study

It is helpful for students to gain experience with conversions. One way to accomplish this is to have them convert some distances they are familiar with to their own student minute. They may also find it interesting to convert the distance to some stars, which are recorded in light years, into kilometers.

Students can also determine their student minute doing other things besides walking heel-to-toe. They may walk normally or run.

## Suggestions for Interdisciplinary Reading and Study

The light year is simply a unit that makes vast distances easier to work with, as explained in the Background section. There are examples of units like this in students' everyday lives. For example, a "dozen" is just another way of representing twelve of something. It is easier to talk about ten dozen eggs than 120 of them. An hour is just an easier way of representing 60 minutes. Ask students to think of other units like this in their own experience. In a writing activity, they could invent their own unit, name it, describe it, and explain how it would be used. For example, what is a "mom minute," as in "Yes, Mom. I'll be there in a minute!"

The concept of distance in the Solar System is sometimes expressed in literature. One example is the poem at the begining of this activity, "A Distant Sun," by Lydia Ferguson.

## Answers to Questions for Students

1. No, all the student minutes should not be the same.
2. The two are similar in that they both involve a time unit in a distance measurement. Both involve measuring how far something can travel in a given amount of time. The major dissimilarity is in the size of the respective units. But also, the light year is a constant because the speed of light is constant. The student minutes will vary because of the variation in how fast different individuals walk as well as variation in how fast one person walks at different times.
3. Again, this answer will depend on the student minute. For example, if a student minute is calculated to be 30 m, then the answer is:

   (3 student minutes) × (30 m/student minute) = 90 m.
4. This answer will vary depending on each different student minute. A student minute of 30 m is reasonable to assume. In this case, the answer would be:

   5,000 m ÷ 30 m/student minute = 166.7 student minutes.
5. Assuming 30 m for the student minute, it would take the student 900 m/30 m = 30 student minutes to reach the friend's house. Therefore, the student should get there just as the friend is leaving.

## The Planets

Across
your dark ocean
the chilled planets journey.
Wanderers of night, they travel
the paths

of their
curving orbits:

Tiny Mercury, Mars,
Venus, bright-ringed Saturn and Earth,
Neptune,

Pluto,
Uranus and
Jupiter, swathed in his
many-colored cloak, his red eye
flashing.

*Myra Cohn Livingston*

BEST COPY AVAILABLE

# Solar System Scale

### Objective

The objective of this activity is to build a scale model of the planetary distances in the Solar System.

### Materials

For each group of students:

- about 100 m of string
- masking tape
- 10 flags
- measuring tape (30 meters or more preferably)
- marker

SCILINKS. THE WORLD'S A CLICK AWAY

Topic: solar system
Go to: *www.scilinks.org*
Code: PESA29

## Background

Sizes and distances in the Solar System are difficult to visualize. The distance from the Sun to Earth is 150 million km. The diameter of Jupiter is 140 thousand km. Both of these measurements are so much larger than anything you ever see that they are difficult to imagine. But there is another way of thinking about the Solar System that is much simpler. It involves reducing all the sizes by the same amount: for example, dividing all the sizes and distances by two. These new values can be used to make what is known as a **scale model**.

Examples of scale models are all around. Model railroads are scale models of trains. A globe is a scale model of Earth. Figure 1 on page 31 shows a scale model of the relative sizes of the planets, but their relative distances are not drawn to scale. The advantage of scale models is that they allow us to determine the distance and size of the true object. All that is needed is the **scaling factor** that was used in making the model. For example, if the wheels of a model car are 10 cm in diameter, and the wheels of a real car are 70 cm, then the scaling factor is 70 ÷ 10 or 7. Now, any size in the real car can be determined by looking at the model car. If the door of the model is 20 cm long, then the door of the real car is 20 × 7 or 140 cm long.

Nicolaus Copernicus figured out how to scale the Solar System in 1543. In 1609 Johannes Kepler built a scale model of the Solar System; as his base scale, he used what would later become known as the Astronomical Unit, the distance between the center of mass of the Sun and the center of mass of the Earth-Moon system. Once the true length of an AU was found (150 million km), the scaling factor could be determined and the rest of the distances calculated.

## Procedure

1. Before starting this activity, picture in your mind what you think a scale model of the Solar System will look like and write a brief description of it. See if the model you build meets your expectations.
2. Measure the longest distance you can use, no more than 100 m. Measure this distance to the nearest meter and record it in Data Table 1. This distance will represent the

distance between the Sun and the planet Pluto (that is 39.4 AU or 5.9 billion km).

3. To calculate the distance from the model sun to each model planet, you need to calculate a scaling factor. Determine the scaling factor by dividing the distance from step 2 above by the distance from the Sun to Pluto. Find this distance in Data Table 2. Record the scaling factor in Data Table 1. For example, if the longest distance usable is 78 m, then the scaling factor is 78 m ÷ 39.3 AU = 1.98 m/AU.
4. Multiply the scaling factor from step 3 by the actual distance from the Sun to each of the planets in AU. Use the distances in Data Table 2. Record the answer in the column labeled "scale distance from Sun."

**DATA TABLE 1**

| Largest usable distance (meters) | Distance to Pluto (AU) | Scaling factor (m/AU) |
|---|---|---|
| | 39.4 | |

**DATA TABLE 2**

| Planet | Distance from Sun (AU) | Distance to planet (kilometers) | Scale distance from Sun (meters) | Actual diameter (kilometers) |
|---|---|---|---|---|
| Sun (a star) | n.a. | n.a. | n.a. | 1,391,980 |
| Mercury | 0.39 | 58,000,000 | | 4,880 |
| Venus | 0.72 | 108,000,000 | | 12,100 |
| Earth | 1.00 | 150,000,000 | | 12,800 |
| Mars | 1.52 | 228,000,000 | | 6,800 |
| Jupiter | 5.20 | 778,000,000 | | 142,000 |
| Saturn | 9.54 | 1,430,000,000 | | 120,000 |
| Uranus | 19.2 | 2,870,000,000 | | 51,800 |
| Neptune | 30.1 | 4,500,000,000 | | 49,500 |
| Pluto | 39.4 | 5,900,000,000 | | 2,300 |

5. Measure out a length of string equal to the scale distance to Mercury from the Sun. Do not cut the string, but wrap a piece of masking tape around it at the proper distance and write "Mercury" on it. From that point, continue measuring the same string out to Venus, and mark that spot on the string. Continue doing this for all the planets out to Pluto.
6. Stretch the string out, and then attach a flag to the string at each point where the location of a planet is marked.

## Questions and Conclusions

1. Describe what your model looks like. Is this different from what you pictured in your mind in step 1? If so, how?
2. The nearest star to Earth is Alpha Centauri, 274,332 AU away. Where would this star be placed in your scale model of Solar System distances?
3. What are some of the advantages and disadvantages that you see in using a scale model? Be specific and use examples from this activity.
4. If you were to make a scale model of the Milky Way Galaxy, what scaling factor might you use?

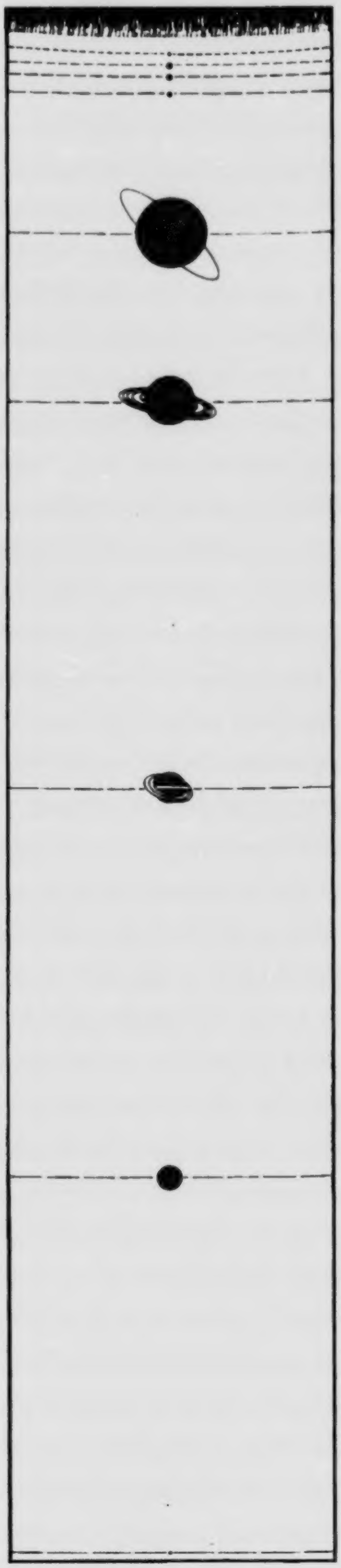


**FIGURE 1**

(Distances not to scale)

# Solar System Scale

### Materials

For each group of students:

- ◊ about 100 m of string
- ◊ masking tape
- ◊ 10 flags
- ◊ measuring tape (preferably 30 meters or more)
- ◊ marker

### Vocabulary

**Scale model**: A model that is proportional in all respects to the object being modeled.

**Scaling factor**: The factor or proportion which, when multiplied by measurements of a scale model, gives the measurements of the object.

**Astronomical unit**: The basic unit of length used to measure distances in the Solar System. It is the distance from the center of mass of the Sun to the center of mass of the Earth-Moon system (149,600,000 km).

## What Is Happening?

Sizes and distances in the Solar System are extremely difficult to visualize. The distance from the Sun to Earth is 150 million km. The distance is so great that there is nothing in everyday experience with which to compare it. Working with distances of this magnitude is extremely difficult for students and adults alike.

One way of dealing with these distances is to use scale measurements, a form of indirect measurement. Many models of buildings and cars use scale measurements. In order to determine true measurements from scale models, one must only know the **scaling factor**. For instance, if a model car is one-seventh the size of the real car on which it is based, then every measurement on the real car is simply the scaling factor, seven, times the corresponding measurement on the model. If the wheels on the model are 10 cm in diameter, the real wheels are 10 cm × 7, or 70 cm.

In this activity, students will build a scale model of the Solar System using true measurements and a scaling factor. The model involves only the distances to the planets, not their sizes. In order to use the same scaling factor for both distance and size, a huge open area would be required. Without such a large area, the sizes of the planets would be much too small to see easily. This fact emphasizes one of the important features of the Solar System—it is mostly empty space. Students need to be made aware of another shortcoming of this model—it represents the planets as all being aligned on one side of the Sun. In reality, such an arrangement of the planets happens infrequently.

## Important Points for Students to Understand

- ◊ The Solar System is largely empty space.
- ◊ A scale model is one way of working with distances that are too large to visualize.
- ◊ As long as the scaling factor is known, true measurements can be determined from scale measurements and vice-versa.
- ◊ The planets are rarely lined up on one side of the Sun.

## Time Management

This activity will probably take more than one class period but less than two. One option is to have the students do all their calculations and string measurement on the first day and then to have them actually lay out the full model on the second day.

Activity 4, "Hello, Out There!" uses the same Solar System scale you have just created. It takes less than a period, so you may want to schedule this at the end of the second day.

## Preparation

If an outdoor space is being used, it is important to do the outdoor part of the activity on a day when the students will be comfortable outside for a long period of time. This activity can be done indoors either in a long hallway, the gymnasium, the cafeteria, the auditorium, or any other large open space.

For additional background information, refer to Reading 4, "Scale Measurements" and Reading 5, "Scouting Earth /Moon."

## Suggestions for Further Study

Encourage students to calculate what the scale size of the planets would be using the same scaling factor as in the first part of the activity. Students may want to pursue the idea of finding a space large enough to lay out a scale model of the Solar System that does have actual models of the planets. An excellent exercise is to have them determine how large that space would be. At the very least, it would be several city blocks long. If such a space is easily accessible, building the model would be very instructive.

Groups of students can be assigned to research individual planets with regard to their important and unique features. Then, once the solar system is laid out, they can conduct a walking tour of the Solar System, stopping at each planet to learn about it.

## Suggestions for Interdisciplinary Reading and Study

Scale models are used in all aspects of Earth science—meteorology, geology, oceanography, and astronomy. The maps used in these areas can be scale models. In each case, the purpose of the model is to depict something which is very large in a much smaller size or something which is very small in a much larger size (like an atom, molecule, or mineral).

Computer models have been particularly useful in meteorology in studying and predicting weather patterns. Many researchers are now trying to create models to study the greenhouse effect and global warming. They are attempting to use these models to predict the future effects of increased carbon dioxide in the atmosphere. These applications point out some of the advantages and disadvantages of models. Encourage students to investigate the use of models and how these models are different from scale models in other areas of Earth science.

The Solar System has been a source of inspiration for many authors. This is particularly true in science fiction and in poetry. Three examples of poems based on the Solar System are "The Planets" (beginning of Activity 3) by Myra Cohn Livingston, "A Distant Sun" (beginning of Activity 2) by Lydia Ferguson, and "Jewels" (beginning of Activity 5) by Myra Cohn Livingston.

## Answers to Questions for Students

1. The inner planets are much closer together than the outer planets. The distance between planets increases as distance from the Sun increases. The model is mostly empty space.
2. The answer will depend on the scale used by the students. If the scale is 1.98 m /AU, then the distance the star would be placed away from the Sun would be

   $$1.98 \text{ m /AU} \times 274{,}332 \text{ AU} = 543{,}178 \text{ m}\ .$$
3. Answers will vary with students. One disadvantage of the model in this activity is not being able to construct a size model on the same scale as the distance model. One advantage is the ability to represent the distances to the planets in a space that allows students to appreciate the emptiness of the Solar System.
4. Answers will vary with students, but the learning will come in thinking about the relative distances within the Galaxy compared to distances within the Solar System. The diameter of the Milky Way is estimated at 300,000 ly. One light year is 63,000 AU. A visible model of these dimensions is nearly impossible to scale.

## Messages

Space sends messages,
mysterious sounds:

Pulsing beats
from distant
neutron stars;

Radio blackouts from a solar flare;

Hissing meteorites
thundering
the
ground;

Signals from puzzling quasars;

Small,
strange
whistlers
from
Jupiter.

*Myra Cohn Livingston*

BEST COPY AVAILABLE

# Hello Out There!

## Background

Everything we see, we see because of light. We see a tree because light reflects off the tree and travels to our eyes. Light travels so fast (300 thousand km/sec!) we have trouble believing that it takes the light any amount of time to travel from the tree to our eyes. For this reason, when we see something happen, we assume that it is happening at that instant. If we go to a baseball game and see a ball being hit, we assume that the ball was hit the moment we saw it happen. But we do not assume the same thing for sound. For example, when we see a bolt of lightning off in the distance, we see the flash of light before we hear the thunder. The light from the lightning reaches us before the sound does because sound travels much more slowly than light (340 m/sec at 15° C).

All forms of light (X-ray, radio waves, microwaves, visible light) travel at the same speed—300 thousand km/sec. Why does light seem to reach us instantly? For two reasons: the distances we are familiar with are very short, and light travels a short distance very fast. When distances become great, the lag time between something happening and us seeing it happen becomes more obvious, just like with the sound of thunder after we see the lightning. For example, the light we are seeing from the Sun actually left the Sun a little more than eight minutes ago.

Stars other than the Sun are much farther away, therefore lag time is much greater. Distances to stars are often measured in light years. A light year is the *distance* that light can travel in one year. If a star is six light years away from Earth, that means that the light leaving the star takes six years to reach us. That also means that the things we are seeing happen on that star actually happened six years ago. In the same way, if there were people on a planet close to the star looking at us, they would see what happened here in 1995, not 2001. They will never be able to see anything more recent than six years in our past.

### Objective

**The objective of this activity is to understand the consequences of light having a finite speed.**

SCILINKS.
THE WORLD'S A CLICK AWAY

**Topic: light**
**Go to: *www.scilinks.org***
**Code: PESA37**

## Procedure

This activity uses the model of the Solar System constructed in the activity "Solar System Scale." Your teacher will give you the directions for the present activity.

## Questions and Conclusions

1. Did you find out what was happening on Earth the instant it happened? Why or why not?
2. What were the consequences of the message from Earth taking time to reach you?
3. How does what you learned in this activity apply to sending information to and receiving information from spacecraft by radio waves? Remember that radio waves are a form of light.

# Hello Out There!

## What Is Happening?

In common experience, it is assumed that light travels over any distance instantaneously. This is because the distances we normally encounter are relatively short, and the speed of light is very great. However, light does take time to travel, and when the distances become great enough, this becomes apparent. An analogy can be made with sound, which travels more slowly than light. If the distance is great enough, there is a lag between seeing an event and hearing the sound that results from it. For example, when we see a bolt of lightning off in the distance, we see the flash of light before we hear the thunder. The light from the lightning reaches us before the sound does because sound travels much more slowly than light.

All forms of light travel at the same speed, 300,00 km/s. Radio waves, one form of light, are used to communicate with spacecraft. The signals now being received from Galileo take hours to reach Earth. The star Sirius (the brightest star as seen from Earth except for the Sun) is 9 ly away. This means that the light now reaching Earth from Sirius left the star nine years ago. If there are people on Sirius watching Earth, they would now be seeing what happened here nine years ago. All this is because light takes time to travel.

This activity is designed to help students understand that light does have a finite speed and that this has consequences for us. In order to grasp the meaning of the activity, it is important for students to understand that light acts as a messenger in the same way that a person can. Both transfer information from one point to another. How quickly the information is transferred depends on the speed of the messenger, whether the messenger is a person or light.

## Important Points for Students to Understand

◊ Light takes time to travel.

◊ Distances must be very great in order for the consequences of the speed of light to become apparent.

◊ A fundamental consequence of the finite speed of light is that we always see a star's past, not its present.

### Materials

For each student:

◊ a piece of candy or other treat (make sure no one is allergic to it)

### Vocabulary

**Speed of light**: According to Albert Einstein's theory of relativity, the speed of light is constant: 299,800,000 m/s (usually rounded to 300,000,000 m/s for purposes of calculation). In this book, 300,000 km/s is used for comprehension and comparison

**Speed of sound**: This varies depending upon the conditions through which sound moves, such as the density and the temperature of the medium. For the purpose of this activity, the speed of sound at 15° C in air is 340 m/s.

**Radio wave**: Like visible light, this is a form of electromagnetic radiation ranging in wavelength from 1 cm to 100 km. Radio waves are low in energy and are used for, among other things, communication with spacecraft. Like all electromagnetic radiation, radio waves travel at the speed of light.

## Time Management

This activity will take much less than one class period. It may be possible to do it on the same day as day two of the activity "Solar System Scale."

## Preparation

This activity should be done in conjunction with Activity 3, "Solar System Scale," or a similar activity on the Solar System. It also assumes that the students are familiar with a light year, as described in Activity 2, "Time Traveler." Assuming some kind of scale model of the Solar System has been built (for example, the one in Activity 3, "Solar System Scale,") there is very little preparation required other than buying the candy for the students. Time may be saved by dividing the students into their planet groups and designating the messenger prior to the activity.

For additional information, refer to Reading 2, "What is a Light Year?" and Reading 3, "Hubble Space Telescope."

## Instructions

1. Select a volunteer or designate a student to be the "electromagnetic messenger."
2. Divide the class into three or four groups and position one group at each of the following planets in your scale model of the Solar System: Mars, Saturn, Uranus, and/or Pluto. Have the students face *away* from Earth.
3. Tell the class that you (the teacher) will be on Earth sending out radio messages into the solar system via the electromagnetic messenger.
4. The electromagnetic messenger will walk heel-to-toe. The students must also walk heel-to-toe when they travel.
5. Since sound cannot travel in outer space, there must be no talking.
6. Send the messenger out into the solar system with a card for each planet that is inhabited. Each card should read, "Mr./Ms. ________ is on Earth handing out a limited amount of candy to hungry astronauts. Go to Earth if you want some candy. Remember, you must walk heel-to-toe, and NO TALKING!" Students must read the message silently.
7. As students arrive, hand each one a piece of candy inconspicuously. When the last group arrives, tease them that you

have run out of candy, but don't forget to give it to them later.

## Suggestions for Further Study

Encourage students to come up with a more elaborate skit to demonstrate consequences of light having a finite speed. This would be an excellent opportunity for students to work in cooperative learning groups. Their group work could be an assessment technique to evaluate whether or not the students grasp the concept.

Have students investigate how astronomers deal with the fact that what they see from stars happened years ago. How do they solve the problem of never being able to see what is happening in a star's present?

## Suggestions for Interdisciplinary Reading and Study

Light is electromagnetic radiation. It includes infrared, visible, ultraviolet, and X-rays, and all travel at exactly the same speed. The various forms of light have both harmful and helpful effects. X-rays revolutionized diagnostic medicine. Too much X-ray radiation, however, has been shown to be harmful. Students can investigate the uses of all the different forms of light and their effects on humans.

Various forms of light provide valuable information for astronomers about the Universe. The idea behind the Hubble Space Telescope was to place a device to gather radiation (ultraviolet, visible, and infrared) above the atmosphere where it could get an unobstructed picture of these types of light from objects in space. When light travels through the atmosphere, it can be refracted, reflected, or absorbed, making it difficult to get an accurate picture of the light from planets and stars with a ground-based telescope. In orbit around Earth, Hubble receives light that is unaffected by Earth's atmosphere. See Reading 3, "Hubble Space Telescope," for a more detailed description.

The idea of seeing a star's past brings up the topic of time travel. In a sense, we are going back in time when we observe any star because we see the star's past as though it were the present. Time travel is a popular theme in science fiction. Madeleine L'Engle's *A Wrinkle in Time* is an account of travelling through time between the planets. The poem "Messages" by Myra Cohn Livingston at the beginning of this activity describes some of the different messages we receive from space. Encourage students to investigate the phrases "pulsing beats from distant neutron stars" and "radio blackouts from a solar flare" from the poem.

A writing activity that integrates astronomy and geology could be inspired by the following scenario. "A huge mirror has been discovered fifty million light years from Earth in space. With your telescope, you can focus on the mirror and see a reflection of Earth. Your telescope is so powerful that you can make out as much detail as a small river on Earth. Write an essay that describes what you would see happening on Earth and when in Earth's past these things would have happened." (This would be 100 million years ago, as light reflected from the Earth had to travel 50 million years to reach the mirror, then another 50 million to reach the telescope.)

While not apparent in this activity, light can be modeled as a wave (though it also behaves in some ways like a particle). Waves have relevance in other areas of Earth science besides astronomy. Some geologists study waves that travel through our planet, particularly those that are the result of earthquakes. It is these waves that cause damage from earthquakes. Sound is another example of a wave. Oceanographers often study ocean waves. These waves have properties in common with light waves. Encourage students to compare and contrast these different waves.

## Answers to Questions for Students

1. No. Because it took time for the messenger to reach each planet. He or she did not get there instantaneously.
2. All students got the message "late." For the farthest students, this meant not getting to Earth before the candy ran out.
3. Any information we send or receive takes time to arrive even at the speed of light. For example, if NASA wants the Galileo spacecraft to make a turn at a certain time, the message must actually be sent hours before that time so that the message will have time to travel.

## Jewels

Space blazes with jewels,
a shimmering ice
of billions of diamonds
dazzles
the Milky Way:

Jupiter, a giant agate,

Uranus, a ball of jade,

Pluto, a luminescent pearl,

Saturn, a halo of rings.

A slice
of moon, a crescent brooch.

Bright rubies splay
Antares

in this
midnight
masquerade.

*Myra Cohn Livingston*

BEST COPY AVAILABLE

# How Far to the Star?

## Objective

The objective of this activity is to investigate the factors affecting parallax.

## Materials

For each group of students:

- ◊ construction paper (or manila folder)
- ◊ pencil
- ◊ metric ruler
- ◊ chalkboard or large sheets of paper (69 cm X 81 cm)
- ◊ chalk
- ◊ scissors (if manila folders are used)
- ◊ tape (if manila folders are used)
- ◊ single hole punch

Topic: parallax/angular diameters
Go to: *www.scilinks.org*
Code: PESA45

## Background

The dimensions of objects can be measured in two ways—directly and indirectly. A tape measure is an example of a device used to measure things directly. **Direct measurements** are made by stretching a tape or placing a ruler next to an object to find out how long it is. Direct measurements are usually made on objects that can be handled. When objects are too big or too far away to be handled, indirect measurements must be made.

There are several forms of indirect measurement. Scale measurements and angular measurements are discussed in Activity 3, "Solar System Scale" and Activity 1, "It's Only a Paper Moon," respectively. Another form uses the parallax effect. This effect is easily demonstrated. Hold up your thumb at arms length, and with one eye closed, line up your thumb with some object in the background. A tree or a telephone pole will work well. Without moving your thumb, switch eyes. Your thumb appears to have moved relative to the objects in the background of your view. This is the **parallax effect**—the apparent movement of an object when viewed against a stationary background from two different points. The two different points in this example were just your eyes. The fact that we have two eyes allows our brain to take advantage of parallax in judging distances.

The parallax effect is often used by surveyors to measure relatively small distances, for example, when building roads. Direct measurements could also be used for these distances but not for distances to objects that are too far away for humans to reach, like the stars. The parallax effect is one of the few ways we have to measure these cosmic distances from here on Earth.

In this activity, you will investigate the factors that affect parallax.

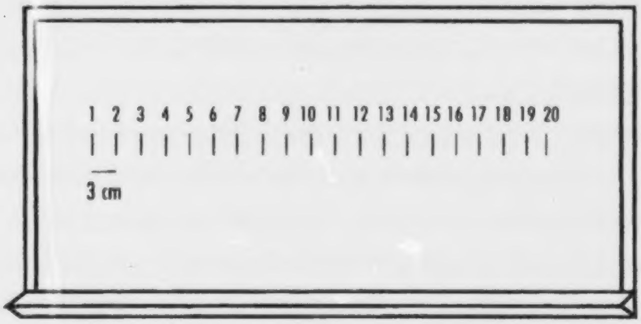


FIGURE 1

## Procedure

**Experiment 1**—In this part of the activity, you will determine the effect on parallax of the distance of the object from the observer.

1. Draw a series of equally spaced vertical lines three centimeters apart across the chalkboard and number them in order as shown in figure 1. Twenty of these lines should be enough.

2. Have one student stand 2.1 m from the chalkboard and hold up a pencil at arm's length (their arm should be parallel to the board). Now, you move back away from the person holding the pencil and away from the chalkboard the distances specified in Data Table 1. Be sure that the student holding the pencil stays in the same place.
3. Close your left eye and look at the pencil with your right eye. In Data Table 1, make a mark below the number of the line where you see the pencil.
4. Now, close your right eye and look at the pencil with your left eye, being careful not to move your head. Make another mark for where you see the pencil with your left eye. Repeat steps 3 and 4 for each distance.

The change in position of the object as seen against the lines will be called "parallax." For example, if you see the pencil in front of line number 3 with your right eye, but it is in front of line number 9 when looking with your left eye, this is a parallax of 9 – 3 = 6.

A partially completed data table might look like the one below.

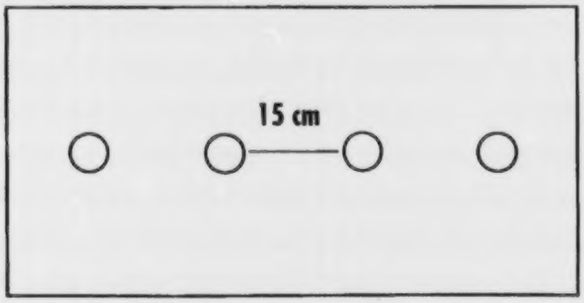
## DATA TABLE EXAMPLE

| Distance from pencil | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | Parallax |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 meter | | | \| | | | | | | \| | | | | | | | | | | | | 6 spaces |

**Experiment 2**—In this part of the activity, you will determine the effect on parallax of the distance between the two points of observation—the baseline.

1. Find a piece of cardboard or stiff construction paper and punch four holes in it 15 cm apart as shown in figure 2. A manila folder torn in half at the fold and taped end to end works well for this.
2. Have someone hold this paper at eye level for you in one place 3 m from the chalkboard. This paper should not move.

**FIGURE 2**



You will be making all of your observations from the same distance from the chalkboard.

3. Again, have someone hold the pencil for you in front of the chalkboard with the lines on it, but this time have them hold it 1.8 m from the board.
4. Look at the pencil against the lines through the first hole with one eye and then through the second hole with the same eye. Record the parallax in Data Table 2.
5. Repeat step 4 for the first and third holes and for the first and fourth holes. Record the parallax each time in Data Table 2.

**DATA TABLE 1**

| Distance from pencil | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | Parallax |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 meter | | | | | | | | | | | | | | | | | | | | | |
| 2 meters | | | | | | | | | | | | | | | | | | | | | |
| 3 meters | | | | | | | | | | | | | | | | | | | | | |
| 4 meters | | | | | | | | | | | | | | | | | | | | | |

**DATA TABLE 2**

| Baseline | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | Parallax |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 cm | | | | | | | | | | | | | | | | | | | | | |
| 30 cm | | | | | | | | | | | | | | | | | | | | | |
| 45 cm | | | | | | | | | | | | | | | | | | | | | |

## Questions and Conclusions

1. What is the effect on parallax of increased distance to the object being observed?
2. Is it possible that you could move so far away that there would be no parallax?

3. What is the effect of an increased baseline on parallax?
4. What would happen to parallax if you:
    a. increased baseline and decreased distance to the object?
    b. decreased baseline and increased distance to the object?
    c. increased baseline and increased distance to the object?
    d. decreased baseline and decreased distance to the object?
5. Hold a sharpened pencil in each hand at arm's length and point them toward each other. With both eyes open, try to touch the points of the pencils together. Now close one eye and try to touch the points again. What happened? Why?

# How Far to the Star?

## What Is Happening?

Measurements of distance are made either directly or indirectly. When a meter stick or similar instrument is held to an object in order to measure it, a direct measurement is being made. However, when objects are too far away to reach or too big to handle, indirect measurements can be made. One type of indirect measurement of distance takes advantage of the **parallax effect**.

The parallax effect is a phenomenon in which an object being observed against a stationary background appears to move when observed from two different points. The effect is easily demonstrated by lining up your thumb with some object in the distance, viewing your thumb with one eye and then with the other. The thumb appears to move against the background. The brain uses the parallax effect in depth perception. This is possible because humans have two eyes set apart by some distance.

The two main factors that determine the magnitude of the parallax effect are the distance to the object being observed and the distance between the two points of observation, known as the baseline. As distance to the object increases, parallax decreases. For this reason, parallax is helpful in observing the closest stars. As baseline increases, parallax increases. The largest baseline achievable on Earth is the diameter of Earth's orbit around the Sun. To do this, one observation is made, and then a second observation is made six months later. This largest baseline is necessary to measure the distance to the closest stars.

In this activity, students will investigate the effect of distance to the object and baseline on parallax.

## Important Points for Students to Understand

- ◊ Distances and sizes in astronomy are often too great to measure directly.
- ◊ Parallax is one form of indirect measurement.
- ◊ Parallax is the apparent shifting of an object when viewed against a stationary background from two different points.
- ◊ Parallax can be used to measure the distance to objects that are too far to measure directly.
- ◊ The magnitude of the parallax effect depends on two factors—distance to the object being observed and distance between the two points of observation (baseline).

### Materials

For each group of students:

- ◊ construction paper or manila folder
- ◊ pencil
- ◊ metric ruler
- ◊ chalkboard or, as an alternative, large sheets of paper (69 cm X 81 cm)
- ◊ chalk
- ◊ scissors (if manila folders are used)
- ◊ tape (if manila folders are used)
- ◊ single hole punch

### Vocabulary

**Direct measurement**: A measurement made using an instrument applied directly to the object or distance being measured.

**Indirect measurement**: A measurement made by other than direct means. Physical proximity to the object or distance is not necessary. Examples of indirect measurement include angular diameter and parallax.

**Angular diameter**: The measure of an object's diameter in degrees of an arc rather than in linear measurement units. This is a type of indirect measurement. Angular diameters are used to calculate diameters of objects in the Solar System.

**Parallax effect**: Usually referred to as "parallax," it is a phenomenon in which an object appears to change positions against a background when viewed from two different points.

**Baseline**: The distance between the two points of observation when measuring parallax.

## Time Management

This activity will take one class period or less. It could be spread out over two days in a couple of ways. First, if there is only one chalkboard in the room, it will be difficult for all students to participate at once. Alternatively, the students could make their twenty lines on large sheets of paper and fasten these to the wall. This could be done on the day prior to the activity. Second, the pieces of stiff paper with four holes in them could be constructed ahead of time. If both of these things are done, taking the measurements should consume less than half a class period.

## Preparation

Be sure that the room is large enough for all students to work at the same time. It is helpful to mark in advance the spaces where students or groups of students can work. An alternative to having students draw the lines on the board is to draw them on adding machine tape and then attach it to the wall. This can be done prior to the activity. Have all materials ready and centrally located for distribution. Students will need to work in groups of three in this activity. Group them before class to save time.

For further information, refer to Reading 3, "Hubble Space Telescope," and Reading 6, "The Parallax Effect."

## Suggestions for Further Study

Students may want to determine the actual distance at which they can no longer detect a parallax with just the distance between their eyes as the baseline. They may also like to experiment outdoors with larger distances and baselines. Rather than using lines on the chalkboard, they can use trees or other landmarks as their background.

Parallax is the fundamental first step for finding distances to stars. To find the distance to planets, parallax has been replaced by methods such as bouncing a radar beam off a planet and observations from space missions.

There is another way to demonstrate parallax that involves the students in a whole-class activity. It is also a model of the way parallax is used to measure the distance to stars. Take the whole class outside in a large open space—a soccer field, for example. Arrange them as shown in figure 3. One student is designated as the near star which will be observed. About half the class stands three or four meters behind this student representing the distant stars. They will be the stationary background against which the near star will be observed. Fifteen to twenty meters on the other side of the "near star," the teacher stands with the other half of the class arranged in a circle around him or her. The teacher represents the Sun and the students represent Earth at different positions in its orbit around the Sun. Have the students walk around the teacher in a circle and make observations of the near star. Ask them to concentrate on how the near star appears against the background stars from different points in the circle.

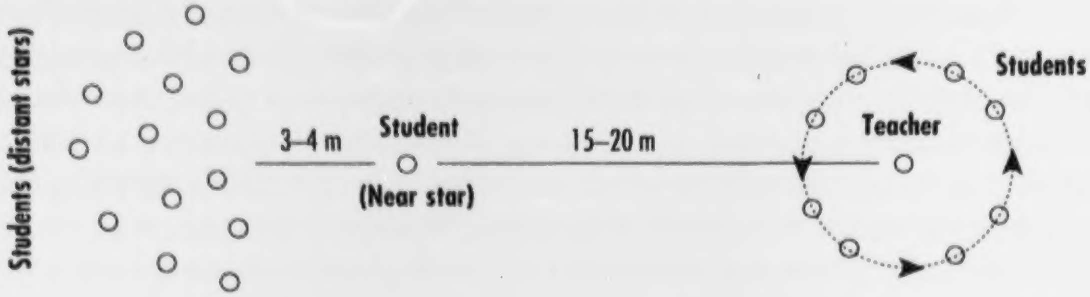


FIGURE 3

## Answers to Questions for Students

1. As distance to the object increases, parallax decreases.
2. The obvious and acceptable answer is "yes." The correct answer is actually "no." The parallax is always there. It becomes too small for us to detect it, but it is always there.
3. As baseline increases, parallax increases.
4. a. Parallax would increase.

   b. Parallax would decrease.

   c. The answer depends on how much each factor was changed. The way the two factors are being changed, they offset each other. Therefore, parallax may increase, decrease, or stay the same.

   d. The same answer as c.
5. The students should not be able to touch the pencil tips together with one eye closed. The reason: with one eye closed, there is only one point of observation and the brain cannot take advantage of parallax. Therefore, it is much more difficult to tell which pencil is closer and which is farther away. This makes it extremely difficult to touch their points.

## Stars

Alone in the night
  On a dark hill
With pines around me
  Spicy and still,

And a heaven full of stars
  Over my head,
White and topaz
  And misty red;

Myriads with beating
  Hearts of fire
That aeons
  Cannot vex or tire;

Up the dome of heaven
  Like a great hill,
I watch them marching
  Stately and still,

And I know that I
  Am honored to be
Witness
  Of so much majesty.

*Sara Teasdale*

BEST COPY AVAILABLE

# Solar System Soup: The Formation of the Solar System

## Background

Over the last four centuries, many theories have been formulated to explain the origin and evolution of the Solar System. Today, the theory most commonly held by scientists is known as the **accretion theory**. The theory was originally formulated in the 1940s but it has been refined over the last few decades.

The theory explains that the Solar System began to form at a time when the Sun had acquired enough mass to begin to attract material from what is known as the **interstellar medium**. The interstellar medium is simply the gas and dust that are spread throughout our galaxy. Since the Sun was spinning when it began to attract the gas and dust, what originally formed was a huge rotating disc of material with the Sun at its center. Astronomers believe that this disc looked very much like the satellite pictures of hurricanes which you have probably seen on television weather reports. Over billions of years, the material in the disc accreted, or clumped together, to form the planets presently in the Solar System. Prior to the accretion theory, no one could explain why the planets farther away from the Sun revolved more slowly than the ones closer to the center of the Solar System.

This activity will model what the very early Solar System would have looked like, as predicted by the accretion theory, and demonstrate that the material on the edge of the disc revolves more slowly than the material at the center.

## Procedure

1. Fill a bucket (or comparable container) three-fourths full with water.
2. Using the graduated cylinder, measure about 15 mL of vermiculite and pour it on top of the water.
3. Stir the mixture vigorously with a stirring rod in a circular motion. When you have a funnel-shaped pattern in the water, stop, remove the stirring rod, and observe.
4. In the space provided on the following page, sketch the

### Objective

The object of this activity is to observe a model of how the Solar System would have originated according to the accretion theory.

### Materials

For each group of students:

- ◊ 1 stirring rod
- ◊ 1 bucket (11 L) for student exercise
- ◊ basin for collecting used water
- ◊ 15 mL of vermiculite

SCILINKS.
THE WORLD'S A CLICK AWAY

Topic: origin of the solar system
Go to: *www.scilinks.org*
Code: PESA53

pattern of vermiculite that you observe. Label what parts of the pattern might form the inner planets and outer planets of a Solar System.

**Sketch of pattern of vermiculite in bucket**

## Questions and Conclusions

1. What did you observe happening to the vermiculite once you stopped stirring the water?
2. Describe the pattern of vermiculite on the surface of the water.
3. Did all of the vermiculite spin around in the bucket at the same speed? If not, what parts spun faster and what parts spun more slowly?
4. Why did the vermiculite eventually slow down and stop? Why has the same thing not happened to the Solar System?
5. Think about how big your bucket of water and vermiculite is compared to the size of the Solar System. Why do you think it took millions of years for the Solar System to form? Can you think of reasons other than size?

# Solar System Soup: The Formation of the Solar System

## What Is Happening?

Although many theories have been formulated to explain the origin and formation of the Solar System, the one most commonly held among astronomers is the **accretion theory**. This theory maintains that the Solar System began to form when a rotating interstellar cloud of gas and dust collapsed under its own gravity. This **protosun** was already rotating. Therefore, as it collapsed, it began to rotate faster and consequently formed a huge flat disc of gas and dust. The gas and dust were not evenly distributed, but were in disconnected parts throughout the disc. The German physicist Baron Carl Friedrich von Weiszacker proved that in such a disc, the outer parts would revolve around the center of the disc more slowly than the inner parts. Later work showed that, over time, the disc would become even more clumpy (disconnected), and eventually these clumps would become dense enough to fall together under their own gravitation. The clumps then evolved into the planets, according to the accretion theory.

One problem with the accretion theory is that the Sun has been found to rotate more slowly than the theory would predict. If the disc spins faster as it collapses, the theory predicts that the Sun should spin faster than is actually observed. This problem was solved in the early 1960s with the discovery of the **solar wind**. This is the stream of charged particles that the Sun is constantly emitting. The Sun's magnetic field is like the spokes of a bicycle wheel carrying streams of charged particles along with it as it spins. This slows the Sun down. This phenomenon, referred to as **magnetic braking**, is the reason why the planets now have most of the rotational momentum in the Solar System rather than the Sun itself.

This activity is designed to show students the pattern that is formed when disconnected material begins to spin. They will see how the outer parts of the spinning disc revolve relatively slowly, and they may even see some of the material begin to clump together into "planets." Be sure the students understand that, unlike the theorized "clumping" of planets due to gravity, the

### Materials

For the class:

- ◊ 1 bag of vermiculite
- ◊ containers of water placed centrally in the room
- ◊ 100-mL graduated cylinder
- ◊ 1000-mL beaker or comparable container for overhead demonstration, if desired

For each group of students:

- ◊ 1 stirring rod
- ◊ 1 bucket (11 liters) for student exercise
- ◊ basin for collecting used water
- ◊ 15 mL of vermiculite

### Vocabulary

**Accretion theory**: A theory formulated in the 1940s by astronomers to explain the formation of our Solar System. According to this theory, material in a disc rotating around a newly formed sun accreted or clumped together to form the planets.

**Interstellar medium**: The gas and dust spread throughout interstellar space. It is concentrated in a spiral arm pattern.

**Protosun**: An early stage of star formation in which a large cloud of interstellar medium is contracting under its own gravity.

**Solar wind**: A stream of electrically charged particles that is constantly flowing outward from the Sun. Near Earth it is traveling at about 600 km/s.

**Magnetic braking**: The slowing of a star or planet's rotation due to the interaction between its magnetic field and surrounding ionized material.

clumps they observe in the vermiculite are *not* due to gravity, but to cohesion of the vermiculite.

## Important Points for Students to Understand

- ◊ While many theories concerning the origin of the Solar System exist, the one most commonly held by scientists is the accretion theory.
- ◊ The disc from which the Solar System formed was not solid like a discus. It was made of disconnected material as demonstrated in this activity.
- ◊ In a disc such as the one from which the planets formed, the outer parts of the disc revolve more slowly than the inner parts.
- ◊ Material rotating in a disc such as the one the Solar System formed from will eventually form clumps due to gravity and the differential speed of revolution. The clumps then become massive enough to attract other material gravitationally, forming a sphere.

## Time Management

This activity will take less than one class period since it does not require data collection and does not take long to set up. In order for the activity to take even less time, it may be done as a teacher demonstration by simply placing a beaker containing water and vermiculite on an overhead projector. The image of the rotating disc will be projected on the screen, and you can point out the relevant features.

## Preparation

Prior to the class, place the buckets, graduated cylinder, stirring rods, and vermiculite in a central location. Vermiculite can be obtained from most garden stores. Have the students come and collect their materials, measuring out the vermiculite before returning to their seats. Ideally, there would be a sink in the room from which to get water. Alternatively, the teacher may fill the buckets before class or have a large enough container of water to supply all the groups.

## Suggestions for Further Study

While the accretion theory of the origin of the Solar System is the predominant one today, this has not always been the case. Other recorded theories date back to the 1600s. Students may be interested in investigating some of these. Many introductory astronomy books contain some detail about early and competing theories. Studying these theories could lead easily into a discussion of Kepler's laws.

One drawback of this experiment is that the disc eventually stops rotating unless stirred periodically. Such stirring, however, disturbs the phenomenon being observed. A solution is to place a magnetic stir bar on the bottom of the beaker or bucket and use the type of hot plate that also stirs. Using heat is not required. Such an arrangement allows students to observe what happens to the vermiculite over an extended period of time.

## Answers to Questions for Students

1. Students should see a pattern form in the vermiculite that resembles a satellite photograph of a hurricane. They will also see the disc of material slow down and stop.
2. The vermiculite will probably not be evenly distributed in the disc. Most of it will be concentrated in the center, becoming less and less dense toward the outer edge of the disc.
3. All the vermiculite should not spin at the same speed. Students should see the inner parts of the disc spinning more rapidly than the outer parts.
4. The vermiculite is floating on water. The water is in contact with the sides and bottom of the bucket creating friction. This friction causes the water and, therefore, the disc to stop spinning. Wind resistance is also a factor but not nearly as important as the friction between water and bucket. The same thing does not happen in the Solar System because there is essentially no friction between the planets and anything else.
5. Finding the answer to this question will require some thought and research on the part of the students. Size, thin distribution of matter, and opposing gravitational forces are some factors that could have influenced the formation of the Solar System.

## Red Sky

Red sky at night, sailors delight
Red sky in the morning, sailor take warning.

Evening red and morning gray
Sets the traveler on his way;
Evening gray and morning red
Brings down rain upon his head.

*(folklore)*

BEST COPY AVAILABLE

# The Goldilocks Effect or "This Planet Is Just Right!"

## Background

Earth is the only planet in the Solar System that supports life. Neither Venus nor Mars, Earth's closest neighbors, is habitable. One of them is far too hot and one is far too cold. Mars has practically no oxygen in the atmosphere and most of the water is tied up in polar ice caps and permafrost. On Venus, the temperature stays around 454° Celsius. The highest temperature ever recorded on Earth was 58° Celsius in El Aziza, Libya on September 13, 1922. If Earth were either closer or farther away, life as we know it never would have evolved.

In this activity, you will investigate the way distance from a light source affects temperature—one of the many reasons why Earth is "just right" in its ability to support life.

## Procedure

1. In this activity you will find where on the meter stick a thermometer should be placed so that the temperature it measures matches a target temperature your teacher specifies before the experiment begins.
2. Place the meter stick on a table. Place the lamp at the end of the meter stick so that light is aimed down along the meter stick as shown in figure 1.

### Objective

The objective of this activity is to investigate the relationship between distance from a light source and temperature and to apply this relationship in understanding why life is possible only on Earth in our Solar System.

### Materials

For each group of students:

- 4 Celsius thermometers
- meter stick
- reflector lamp (equipped with clamp) or gooseneck lamp with 75-watt bulb
- watch or clock

SCILINKS. THE WORLD'S A CLICK AWAY

Topic: the Earth or dement zone
Go to: *www.scilinks.org*
Code: PESA59

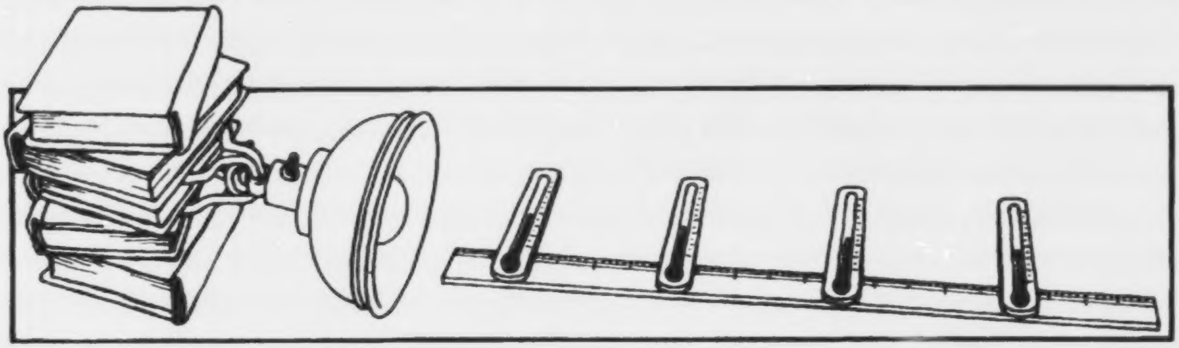


FIGURE 1

3. Place the thermometers down flat on the meter stick in positions where you think one of them will have a tempera-

ture that will match the target temperature. Each thermometer represents a possible distance for Earth from the Sun. Be sure that the bulb of each thermometer is on the meter stick. Record the distance of each thermometer from the end of the meter stick that is next to the lamp in the Data Table.

**DATA TABLE**

| Trial | Thermometer | Distance to thermometer | Temperature (° C) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Start | 3 min. | 6 min. | 9 min. | 12 min. | 15 min. |
| 1 | 1 | | | | | | | |
| | 2 | | | | | | | |
| | 3 | | | | | | | |
| | 4 | | | | | | | |
| 2 | 1 | | | | | | | |
| | 2 | | | | | | | |
| | 3 | | | | | | | |
| | 4 | | | | | | | |
| 3 | 1 | | | | | | | |
| | 2 | | | | | | | |
| | 3 | | | | | | | |
| | 4 | | | | | | | |

4. Record the starting temperatures for each thermometer in the Data Table. Turn on the lamp and record temperatures for each thermometer every 3 minutes until no temperature change is seen in any thermometer. ***Caution: The lamp and reflector will become hot.***
5. If none of the final temperatures are the same as the target temperature, graph your results, plotting temperature versus distance. Then try to predict at what distance you should place thermometers when you repeat step 4 so that one of the final temperatures matches the target temperature. If

necessary, continue repeating steps 3 and 4 until one of the thermometers reaches the target temperature.

## Questions and Conclusions

1. What happened to the temperatures when the light was turned on?
2. How difficult was it to find the position on the meter stick where the final temperature matched the target temperature? Why was this so?
3. How does distance from a source of light (the Sun, for example) affect temperature?
4. How would the temperatures on the gaseous planets (all the planets beyond Mars except Pluto) compare to the temperatures on Mercury, Venus, Earth, and Mars (the terrestrial planets)?
5. What are some other factors besides distance from the Sun that determine the average temperature of the planet?
6. Based on your observations, do you think we could still live on Earth if the planet moved very much toward or away from the Sun? Why?
7. If Mars or Venus were somehow moved so they were now the same distance from the Sun as Earth, do you think we could live on either of them? Why or why not?

# The Goldilocks Effect or "This Planet Is Just Right!"

### Materials

For each group of students:

- ◊ 4 Celsius thermometers
- ◊ meter stick
- ◊ reflector lamp (equipped with clamp) or gooseneck lamp with 75-watt bulb
- ◊ watch or clock

### Vocabulary

**Clement zone**: A narrow range of distances from the Sun in which conditions are suitable to sustain life as we know it.

## What Is Happening?

The fact that Earth is the only planet in the Solar System that we know supports life is a consequence primarily of its distance from the Sun. If Earth were only *2* percent of its present distance farther away from the Sun, it would be like Mars—a permanent "Ice Age" wasteland with a carbon dioxide atmosphere and all of its water tied up in polar ice caps. If Earth were only *5* percent closer to the Sun, it would be most like Venus, a planet many astronomers have described as a "hellish place." The surface temperature on Venus is about 454°C. Earth's distance from the Sun is just right, and practically no other distance will do. Only recently has it been determined that the range of distances from the Sun in which Earth's conditions could have formed is very small compared to the scale of the Solar System. Because of this narrow range (or **clement zone**), Earth's atmosphere is the only one in the Solar System which will allow water to exist in all three states simultaneously—solid, liquid, and gas.

Earth's distance from the Sun has allowed life to flourish here because of one of the properties of light: As the distance from a light source increases, the intensity of the light decreases. That is why in a room with only one light, it becomes increasingly difficult to read a book as you move farther away from the source. The intensity of the light decreases with the *square* of the distance from the source. This means that if you move twice as far away from the source, the intensity of the light will be only one-fourth of what it was. Earth is placed such that it gets just the right intensity of light to allow its unique atmosphere to exist.

This activity is designed to show students that distance from a light source will affect temperature and that the range of distances in which a specific temperature can exist is relatively small.

## Important Points for Students to Understand

- ◊ The intensity of light decreases as you move away from the source.

◊ As the intensity of light decreases, the temperature resulting from that light will also decrease.

◊ The temperature on a planet is primarily a consequence of the planet's distance from the Sun. But there are other factors as well.

◊ The range of distances from the Sun in which life can exist is very narrow.

## Time Management

Including set up and clean up, this activity will take one class period or less. It is suggested that students have another task to do between temperature readings. For example, they could be completing an assignment on planetary comparisons which emphasizes the uniqueness of Earth.

## Preparation

Prior to the class, assemble all the materials in a central location. Make sure that all lamps are working and that none of the thermometers are broken.

Prior to the class period, set up an apparatus and place one thermometer someplace on the meter stick. Turn the light on and allow it to remain on until the temperature on the thermometer no longer rises. Let this temperature be the "target temperature" mentioned in the student instructions. Students will try to determine where on the meter stick to place a thermometer so that its temperature matches the target temperature.

Be sure that thermometers are calibrated. Also, be sure that room temperature does not change much between the time the target temperature is determined and the time the activity is done. If the room temperature changes too much, the target temperature may actually be below room temperature, making the activity impossible. For additional information, refer to Reading 8, "After the Warming," and Reading 9, "Atmosphere, Oceans, Cryosphere, and Hydrologic Cycle."

## Suggestions for Further Study

Some students may want to further investigate the relationship between intensity and distance from a light source. This can be done easily in a room with a single light source and a light meter. This provides an excellent opportunity to use graphing skills, plotting distance versus light intensity.

There are other factors which determine a planet's surface temperature besides light intensity, in particular the atmosphere. The atmosphere affects temperature through a phenomenon known as the greenhouse effect. In addition to extensive literature on this topic, there are activities which demonstrate it quite well, such as Activity 8, "The Greenhouse Effect."

## Suggestions for Interdisciplinary Reading and Study

The "Quotes from Space," appearing at the beginning of Activities 8 and 9, are quotes from astronauts from shuttle and Apollo missions describing what Earth looks like from space. Their accounts provide us with a unique perspective on our planet. The descriptions highlight Earth's beautiful and fragile nature. Encourage students to read these accounts and react to them in small group or class discussions. What do these descriptions make the students realize about Earth that they did not realize before? Readings 7, 9, and 11 will also contribute to students' understanding of the uniqueness and fragility of Earth.

## Answers to Questions for Students

1. All the temperatures rise, but those closer to the light source rise by a greater amount and more rapidly.
2. Answers will depend on the students. It may be difficult to find the position since the range of distances from the light source which accompany the target temperature is small.
3. As distance increases, radiant energy decreases.
4. Since they are farther away, they should be lower than the temperatures of the inner planets.
5. The atmosphere. The amount of liquid water. For example, Earth's atmosphere helps keep a lot of heat in, and the ocean currents moderate temperatures all over the planet.
6. No. Because a very small change in the distance from the Sun leads to very drastic changes in conditions on Earth, most notably in temperature.
7. Answers will vary. There is quite a bit of evidence that neither planet would be habitable even if it were in the position of Earth. Evidence from the geologic record suggests that Earth took billions of years to evolve life-sustaining conditions.

## Quote from Space

. . . One view in particular is awe-inspiring with Africa in the foreground and the whole profile of the Mediterranean very clear. One stares at the whole Mediterranean, looking from outer space much as in an atlas, but not as in a drawing. Much of our most commonly taught history centers around that little sea, a mere patch of the hemisphere, which once seemed to its inhabitants to be the whole world.

Looking into the blackness beyond the sharp, blue-green curve, trying to see even the place where the thin envelope of atmosphere and the solid Earth meet, the curious word "fragile" comes to mind. To be on Earth and think of it as fragile is ridiculous, but to see it from out there and compare it with the deadness of the Moon!

***Astronaut John Caffrey***

BEST COPY AVAILABLE

# The Greenhouse Effect

## Background

Greenhouses are made almost completely of glass for two reasons. First, glass allows the maximum amount of sunlight into the building. Plants need the sunlight for photosynthesis. Second, glass prevents heat produced in the greenhouse from escaping. Clear plastic can serve these same two functions. When materials like glass and plastic let sunlight, but not heat, pass through them, the effect has come to be known as the **greenhouse effect**, which is a form of solar heating. How does the greenhouse effect work?

Visible light is only one form of light. Radiant heat is **infrared light**, another form. When visible light (sunlight) passes through the glass of a greenhouse, it strikes the objects in the building and its energy is absorbed. These objects begin to heat up. As they heat up, they give off radiant heat—infrared light. While visible light can pass through the glass of the greenhouse, the infrared light cannot. This means that the heat given off by objects in the greenhouse is trapped in the building. Therefore, even on cold, *sunny* days, the building can stay warm.

Some gases are like the glass of a greenhouse in that they trap heat. Several of these gases, including carbon dioxide ($CO_2$), water vapor ($H_2O$), nitrogen oxide (NO), and methane ($CH_4$), are present in Earth's atmosphere. The amounts of these gases are increasing daily because of some human activities such as driving cars and burning fuel, and because of such natural processes as decomposition in swamps, where methane is released into the atmosphere from the decomposition of dead plants and animals. At present, the atmosphere traps only a small part of the heat given off by the surface of Earth. As the amount of carbon dioxide and methane increases, however, Earth may become more like a greenhouse, growing warmer as the atmosphere traps more heat.

This activity will model how a greenhouse effect can occur.

## Procedure

1. About 2 cm from the top of each plastic cup, use the hole punch to make a hole big enough for a thermometer to be inserted.
2. Fill each cup with dirt until the dirt is about 2.5 cm below the hole just made.

### Objective

The objective of this activity is to observe and to investigate a model of how light and the atmosphere interact to make Earth suitable for life.

### Materials

For each group of students:

- ◊ two large disposable plastic cups
- ◊ dirt to fill each cup
- ◊ something to prop up thermometers (a slightly smaller cup or stack of books will work)
- ◊ one rubber band
- ◊ two Celsius thermometers
- ◊ hole punch

Topic: greenhouse effect/global warming
Go to: *www.scilinks.org*
Code: PESA67

3. Insert a thermometer through each hole so that the bulb is about 2.5 cm above the dirt and centered near the middle of the cup (see figure 1). ***Caution: Do not force the thermometer through the hole. If it will not go, punch a bigger hole.***
4. Turn the thermometers so that they can be read.
5. Cover one cup with plastic wrap, and leave the other cup uncovered. Secure the plastic wrap on the cup with a rubber band. The final arrangement should look like figure 1.
6. On a sunny day, take the two cups outside at the beginning of the class period, and place them where they will not be disturbed. Stabilize the thermometers so they will not move.

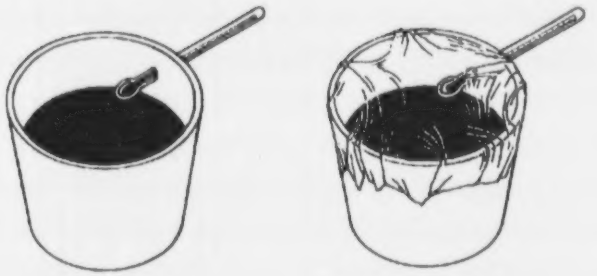


**FIGURE 1**

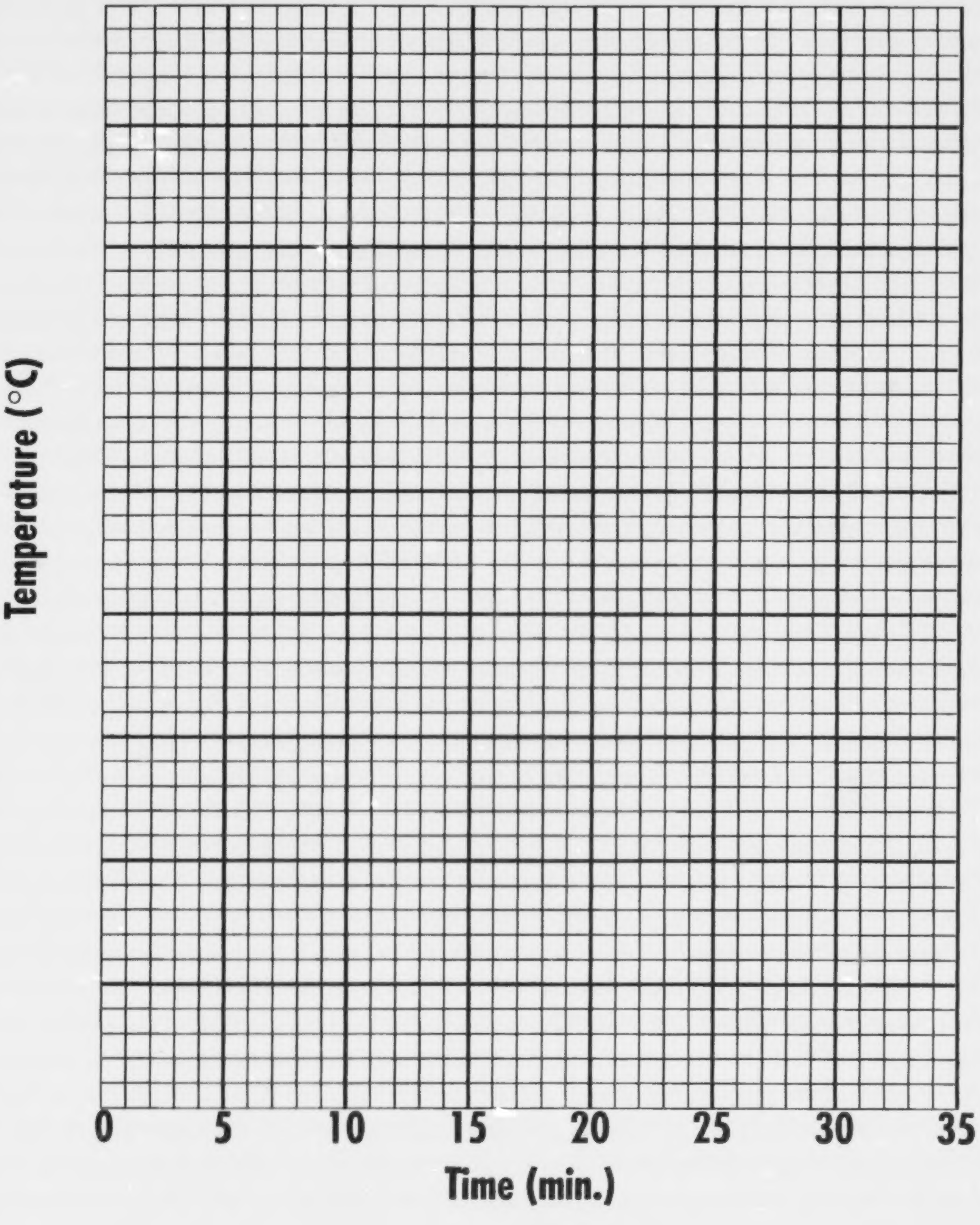
7. Record the initial temperature on each thermometer in the Data Table.
8. Record temperatures every 5 minutes for 30 minutes. During the first five minutes, write a prediction of what you think will happen to the temperatures of the two cups and give a reason for your prediction. Do this in the space below the Data Table.
9. Make a graph for the temperatures in each cup on a sheet of graph paper. Graph the temperatures on the vertical scale and the elapsed time on the horizontal scale. Designate each line as representing either the covered or the uncovered cup.

## Questions and Conclusions

1. This activity is a model of what happens on Earth. What do the dirt and plastic wrap represent in this model?
2. What did you predict would happen?
3. Do your graphs support your prediction?
4. How does what you observed in each cup compare with your prediction? If the two are different, how can you account for this?

**DATA TABLE**

| Time (min.) | Temperature of covered cup (° C) | Temperature of uncovered cup (° C) | Other observations |
|---|---|---|---|
| 0 | | | |
| 5 | | | |
| 10 | | | |
| 15 | | | |
| 20 | | | |
| 25 | | | |
| 30 | | | |
| 35 | | | |
| Total difference in temperature | | | |


Temperature (°C)
0
5
10
15
20
25
30
35
Time (min.)

# The Greenhouse Effect

## What Is Happening?

The term **greenhouse effect** refers to the fact that visible light can pass through glass uninhibited but **infrared light** (heat) essentially cannot. The term was coined because this effect is most evident in greenhouses. The phenomenon is a consequence of the nature and behavior of light.

Light takes the form of X-rays, gamma rays, ultraviolet light, infrared light, radio waves, and microwaves—not just visible light. As objects in a greenhouse absorb light, they heat up and give off infrared light. While visible light can pass through the glass of the greenhouse, the infrared light cannot and it is reflected back in. So the heat given off by objects in the greenhouse stays in the greenhouse.

Some gases in Earth's atmosphere, notably carbon dioxide ($CO_2$), water vapor ($H_2O$) and methane ($CH_4$), act like the glass in a greenhouse. Sunlight passes through the atmosphere, strikes the ground, and the ground begins to heat up. The ground then gives off infrared light, which $CO_2$, $H_2O$, and $CH_4$ partially block from escaping the atmosphere. There has always been a natural and beneficial greenhouse effect operating on Earth due primarily to naturally occurring $CO_2$ and $H_2O$. The problem now is that human activities such as burning fossil fuels, which releases extra $CO_2$ into the atmosphere, and deforestation, which eliminates flora that use $CO_2$ from the atmosphere for photosynthesis, are disturbing the natural balance. As the quantities of these gases grow in the atmosphere they will prevent more and more of the heat from escaping—which may cause the temperature of Earth to rise.

## Important Points for Students to Understand

- Light comes in many forms, not just the visible form which we can see.
- The passage or transmittance of the infrared light (heat) is inhibited by certain things, among them glass, $CO_2$, $H_2O$, and $CH_4$.
- $CO_2$, $H_2O$, and $CH_4$ only partially inhibit the passage of heat. The greater the concentration of the gas, the less heat is allowed through.

### Materials

For the class:

- one large bag of potting soil
- one box of plastic wrap
- graph paper for each student

For each group of students:

- two large disposable plastic cups
- dirt to fill each cup
- something to prop up thermometers (a slightly smaller cup or stack of books will work)
- one rubber band
- two thermometers
- hole punch

### Vocabulary

**Greenhouse effect**: A planet's atmospheric layers act like the glass of a greenhouse, permitting sunlight to pass through and strike a planet's surface but partially prohibiting the escape of heat (infrared light) radiated from that surface. As a result, the atmosphere warms up.

**Infrared light**: Heat or a form of electromagnetic radiation (light) which has a wavelength ranging from 1 $\mu$m to 1 mm. The wavelength of visible light is between 100 and 1,000 times shorter than infrared.

**Radiant heat**: Infrared light.

## Time Management

This activity should take only one class period, but it will take the entire period. You may want to give the students assignments to complete between temperature readings. Time can be saved by having the students set up their cups the day before the activity is to be done. It is important to remember that the success of this activity depends on having a sunny day but not necessarily a warm day.

## Preparation

Prior to preparing the cups, place all the materials in a central location so that students can easily obtain them. Keep track of the weather report and pick out a sunny day on which to do the activity.

Reading 8, entitled "After the Warming," is a concise overview of the greenhouse effect. It includes a description of the phenomenon, some of the research that has been done on it, and a synopsis of opposing views about global warming. Also refer to Reading 10, "The Greenhouse Effect," and Reading 11, "Interaction of Human Activities with the Natural Environment."

## Suggestions for Further Study

Students may want to see what happens if the cups are left out all day long. Do the temperatures continue to rise? If not, why not, and how does this relate to Earth?

This is an excellent place for students to investigate what happens on other planets with regard to the greenhouse effect. Venus and Mars are especially good to research. Students will almost certainly want to know what will happen if the greenhouse effect increases dramatically on Earth. Venus provides a model of what might occur.

Finally, students may want to look into the research that is being done on the greenhouse effect and global warming. This is a controversial topic even in the scientific arena. Have students investigate the human activities that have led to an increase in carbon dioxide in the atmosphere.

## Suggestions for Interdisciplinary Reading and Study

The oceans play a major role in moderating the amount of carbon dioxide in the atmosphere. The gas is dissolved in the ocean and eventually becomes a part of some shells and ocean sediments. Students can investigate research that is being done on the role of the ocean in carbon dioxide regulation.

The greenhouse effect and global warming are societal as well as environmental problems. Solutions based on environmental concerns alone are incomplete. Industrialized societies depend heavily on burning fossil fuels, the chief source of carbon dioxide in the atmosphere. Solutions to these problems must take into account societal and technological factors as well as environmental ones. What would be the impact on the United States and other industrialized countries of shifting away from fossil fuels? What technology would be required to do this? Are there other possible solutions besides alternative energy sources?

## Answers to Questions for Students

1. The dirt represents the surface of Earth. The plastic wrap represents Earth's atmosphere.
2. Predictions may vary slightly. Pay careful attention to what students predict—it will provide clues for what misconceptions exist in your class and give you guidance about whether to extend this activity.

   The temperature in both cups should have increased, but at different rates. As the dirt in each cup gives off heat, the temperature of each increases. In the covered cup, however, the heat does not escape so the temperature rises more rapidly.
3. The students should see a graphical representation of the answer to question 2.
4. Answers will vary.

## Quote from Space

The sight of the ice particles in front of the Shuttle is like . . . fireflies. They're different colors. Some of those sparkles out there are red . . . most of them are white . . . some really bright ones out there. And as the Sun sets on the orbiter, the ice crystals go out. The last few of them turn red. Then they're all red. Then they're gone.

When you look outside and see the black of space and the ice crystals following us around and the sunrise and sunset every hour-and-a-half; [you] look out and see the lightning storms flashing, the cities making their light patterns beneath the clouds, the patterns in the ocean, flying over the Himalayas as we do the last orbits tonight, then I know I'm really in space.

***Astronaut Jeff Hoffman***

BEST COPY AVAILABLE

# Creature Feature

## Background

For as long as we have known that there are other planets in the Solar System, we have wondered if there might be life on them and if they might support human life. The planet that has received most of this attention is Mars. Some surface features of Mars which are visible from Earth have in the past led us to believe that entire civilizations may have once existed there. In 1976 Viking I and II actually landed on Mars and collected soil samples for analysis. The results of these tests did not support the belief that life may have existed on Mars.

Mars and Venus are Earth's closest neighbors. The differences between them are striking. In many ways, Earth can be thought of as the happy medium between the two extremes that Mars and Venus represent. We are aware of many of the forms of life, both plant and animal, that exist on Earth. Imagine that you were able to create an organism that could survive on Venus or Mars. Would it resemble a plant or animal that you are familiar with? What features would it need for life on these planets? In order to answer these questions, you will need to become more familiar with the characteristics of Earth's next door neighbors, Venus and Mars.

### Objective

The objective of this activity is to consider some of the characteristics of Venus and Mars which make the planets uninhabitable for life as we know it.

### Materials

- ◊ construction paper (at least three different colors)
- ◊ scissors
- ◊ glue
- ◊ aluminum foil
- ◊ straws
- ◊ toothpicks
- ◊ paper cups
- ◊ transparent tape
- ◊ floral wire

## Procedure

1. Carefully read and study the following brief descriptions of Venus and Mars.

### VENUS

Venus is the second planet from the Sun, between the orbits of Mercury and Earth. Because it is closer to the Sun than Earth, the sunlight that strikes it is almost twice as intense as that which strikes Earth. The Venusian atmosphere is 96 percent carbon dioxide. This high concentration of carbon dioxide results in a runaway greenhouse effect (see Activity 8) such that the surface temperature on Venus is 477° C. The atmosphere is much "thicker" than Earth's, so much so that the air pressure at the surface of the planet is 90 times that on Earth. It is so thick that only about 25 percent of the sunlight that strikes it passes through to the surface; the remaining 75 percent is reflected to space. Consequently there is a constant eerie, reddish light at the surface of the planet during the day.

The Venusian atmosphere has no oxygen to speak of. It is filled with clouds made of sulfuric acid, a very corrosive substance. The planet rotates slowly compared to Earth. One day on Venus is as long as 117 days on Earth. The surface of Venus is similar to Earth's in composition and density, and Venus is only 5 percent smaller than Earth. Venus is considered more similar to Earth than any other planet in the Solar System.

SCILINKS.
THE WORLD'S A CLICK AWAY

**Topic: Mars**
**Go to: *www.scilinks.org***
**Code: PESA76**

## MARS

Mars, the next planet beyond Earth, is similar to Earth in several ways as well. The tilt of its rotational axis and its rotational speed are almost identical to Earth's. So the Martian day is about the same length as Earth's, and Mars has seasons like Earth. The Martian atmosphere is very thin. The air pressure at the surface is 166 times less than that on Earth. Carbon dioxide constitutes 95 percent of this atmosphere, but unlike Venus there is no substantial greenhouse effect. So the planet is subject to a wide range of temperatures. The temperature can be as low as -128° C or as high as 37° C during a Martian summer. At the north and south poles, the temperatures remain cold enough year-round to maintain permanent ice caps made of frozen carbon dioxide (dry ice). The atmospheric pressure on Mars is far too low to allow the existence of liquid water. It is believed that what water does exist on Mars is frozen either beneath the polar ice caps or in clouds. The surface of Mars is extensively covered with iron oxide (rust) giving the planet its characteristic red color.

2. In your group, design and construct a model of some form of life that could survive on Venus. Be sure to include features that are capable of handling the conditions on Venus as described above.
3. Repeat step 2 for Mars.
4. In your group prepare an explanation of the features of both organisms and designate one or two people in the group to present this to the class.

## Questions and Conclusions

1. What features of Venus make it most unlikely that humans or other forms of life from Earth could survive there?
2. What features of Mars make it most unlikely that humans or other forms of life from Earth could survive there?
3. Could the "life form" that you designed for Venus survive on Earth? Why or why not?
4. Could the "life form" that you designed for Mars survive on Earth? Why or why not?

# Creature Feature

## Materials

For each group of students:

- construction paper (at least three different colors)
- scissors
- glue
- aluminum foil
- straws
- toothpicks
- paper cups
- transparent tape
- floral wire

## What Is Happening?

The purpose of this activity is to help students understand and appreciate the fact that Earth is the only planet in the Solar System that sustains life. With the age of space exploration came the realization that we may one day be able to travel to other planets in the Solar System and the realization that these planets are uninhabitable. Neither the Soviet nor the U.S. missions to Mars and Venus, the planets closest to Earth, have succeeded in finding signs of life past or present on either planet. In this activity, students will consider some of the conditions on Venus and Mars that make these findings plausible. (Although our missions to these planets don't indicate life, some scientists believe that Martian meteorites that have been found on Earth seem to have microfossils—see *www.jpl.nasa.gov/snc*. So far, fewer than 20 of these have been found—and not everyone agrees about what they are, but they have made a big splash in the news.) Hopefully, in the course of the activity students will come to appreciate the uniqueness of Earth and learn the importance of stewardship toward the planet.

"Creature Feature" is well-suited to cooperative learning groups. It is strongly suggested that each group be required to present their creatures to the entire class and explain them.

## Important Points for Students to Understand

- Earth is the only planet in the Solar System that sustains life.
- Through space exploration, we are now aware of specific conditions on Mars and Venus that make the planets uninhabitable.

## Time Management

This activity will require at least one class period for groups to construct and present their creatures to the rest of the class. More time will be required for class and teacher critiques of the creatures.

## Preparation

Be sure to have at least the materials listed above on hand, but try to have even more. The more materials the students have to work with, the more creative their creatures will be. You may want to prepare in advance a rating scheme so that classes can vote on the best creature for Mars and Venus. If the criteria are made known to the students, it may help them to design creatures that directly relate to the conditions on Mars and Venus. It is a good idea to prepare some way to display all the groups' creatures for the entire class. One suggestion is to hang them from the ceiling.

For further information, refer to Reading 9, "Atmosphere, Oceans, Cryosphere, and Hydrologic Cycle," and Reading 11, "Interaction of Human Activities with the Natural Environment."

## Suggestions for Further Study

Earth's conditions and its life forms are interrelated—each impacts the other. For instance, it is believed that as plants developed, they removed some carbon dioxide from the atmosphere and increased the amount of oxygen there. This made conditions more hospitable for other forms of life. We know that human activity is altering the composition of the atmosphere. As an extension to this activity, it would be interesting to have the students consider how their creatures might change the conditions on Venus and on Mars by their existence.

Encourage students to investigate what changes would be necessary to make Mars habitable. Some scientists have suggested that if all the carbon dioxide frozen in the Martian polar ice caps were in the atmosphere, there might be a sufficient greenhouse effect to make the existence of liquid water possible.

## Suggestions for Interdisciplinary Reading and Study

This activity is most appropriate at the end of the astronomy unit as some of the concepts that are used in the descriptions of Mars and Venus, particularly seasons and the greenhouse effect, are covered earlier in the unit. Alternatively, the activity could be used in the study of life science once the relevant concepts from astronomy are understood. As the students' understanding of life science grows, so will their understanding of the severity of the conditions for life on Mars and Venus. Used in this way, the activity could serve as a type of pre- and post-assessment to allow the students' increased understanding of astronomy and life science to be reflected in their "creature" designs.

## Answers to Questions for Students

1. Lack of liquid water, lack of oxygen in atmosphere, high surface temperature, and high atmospheric pressure, among others.
2. Lack of liquid water, lack of oxygen in atmosphere, low surface temperature, low atmospheric pressure, global dust storms, among others.
3. Answers will depend on the students' models.
4. Same as 3.

## Seasons

Winter touches each tree branch,
With icy fingers so very cold.
Suddenly spring comes along
Which will dispel winter's hold.

When summer first approaches,
Balmy breezes will be at play.
Then soon heat and humidity
Will be around awhile to stay.

Autumn's red and golden colors,
Warn us winter is very near,
And so much can be seen
In each season of the year.

***Evelyn Nitso***

BEST COPY AVAILABLE

# Reason for the Seasons

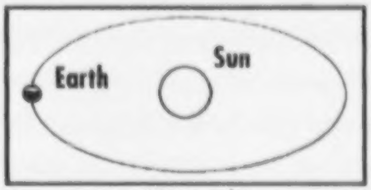
### Objective

The objective of this activity is to understand why Earth has seasons.

## Background

Many drawings of Earth's orbit around the Sun look like figure 1. These are meant to give you a view of a nearly circular orbit seen from the side. Rather than a circle, the shape of the orbit in figure 1 is called an ellipse. Often, however, students mistakenly think that such drawings show Earth's *true* orbit.

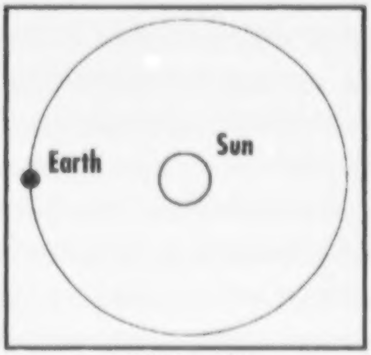
While it is true that Earth does have a slightly elliptical orbit, it is not nearly as extreme as that illustrated in figure 1. That picture makes it look like Earth is much closer to the Sun at some times and much farther away at others. Actually, Earth's orbit looks much more like a circle than an ellipse. Figure 2 is a much more accurate representation of Earth's orbit around the Sun.



(Not to scale)

**FIGURE 1**

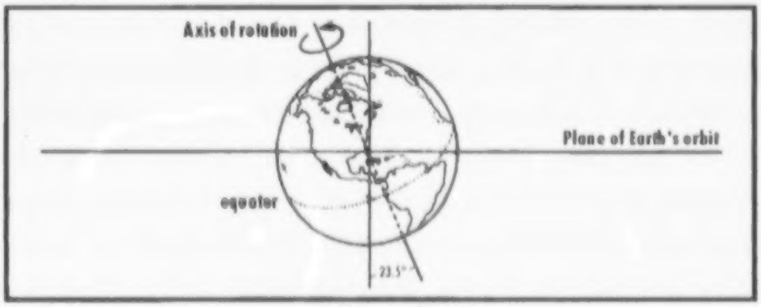
Many people think that the reason Earth has seasons is because its orbit looks like figure 1. They think that when Earth is closest to the Sun, summer occurs, and when it is farthest from the Sun, we have winter. If distance from the Sun determined the seasons, then it should be summer in the southern hemisphere (Argentina, for example) when it is summer in the northern hemisphere (the United States or England), but this is not what happens. When it is summer in the northern hemisphere, it is winter in the southern hemisphere.



(Not to scale)

**FIGURE 2**

The reason Earth has seasons is because of the angle at which it rotates as it revolves around the Sun. Most objects rotate around an axis that is straight up and down, just like when someone spins a ball on his or her finger. But Earth's axis is tilted, as shown in figure 3, and this tilt causes the seasons.

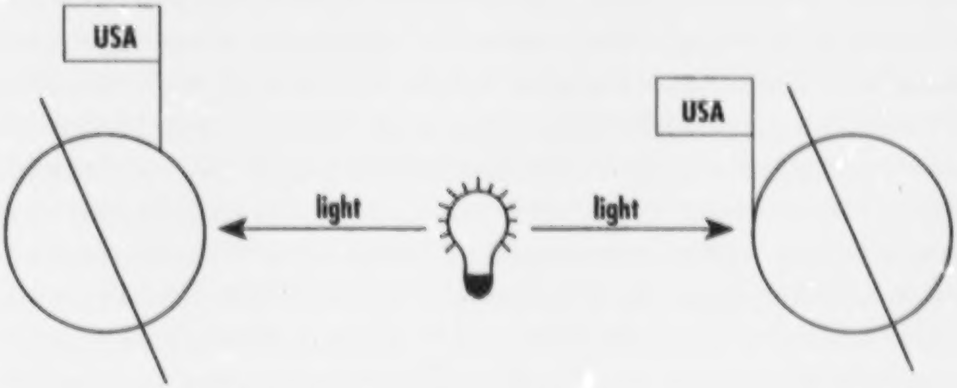


(Not to scale)

**FIGURE 3**

## Procedure

1. Arrange the lamp and globe(s) as shown in figure 4. If you are using two globes, be sure that each is the same distance from the lamp. A minimum distance of 1.5 m from the bulb is recommended.



2. Darken the room.
3. Make and record observations about the intensity of light on the different parts of the globe that are facing the light.
4. Take one globe and walk it through an orbit around the Sun, making sure that you maintain the tilt of the axis and keep it oriented in the same direction. At each position, you may want to spin the globe so that the difference from day and night can be observed.
5. Make and record observations about the brightness of light on the United States as the globe goes through its orbit.

Topic: reasons for the seasons
Go to: *www.scilinks.org*
Code: PESA84

## Questions and Conclusions

1. How did the brightness of light on the United States compare in the first demonstration when there was a globe on each side of the light?
2. How can you account for the differences in the brightness of light?
3. How did the brightness of light on the United States change when the globe was walked around the Sun?
4. At what points in the orbit do you think each of the seasons would occur?
5. When it is summer in the United States, where might it be winter?

6. Do the seasons in other parts of the United States differ from the seasons where you live? Why or why not?
7. If you traveled to Australia right now, what season would it be? Explain.
8. What would be necessary for other planets to have seasons as Earth does?

# Reason for the Seasons

### Materials

For the class:

- ◊ one or two globes mounted so that the axis of rotation is tilted to 23.5° from vertical
- ◊ a bright light source (lamp with at least a 75-watt bulb and without a shade)

### Vocabulary

**Orbit**: The path followed by one body revolving about another body.

**Ellipse**: An oval; a closed curve in which the sum of the distances from two fixed points to any point on the curve is constant.

**Axis**: A straight line about which a figure or body is symmetrical.

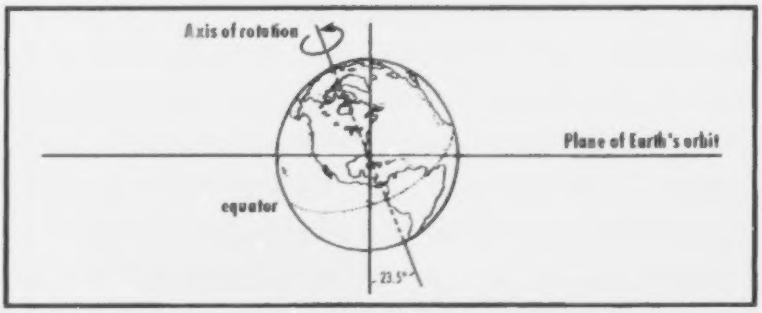
**Rotation axis**: A straight line around which a body rotates.

## What Is Happening?

Earth travels around the Sun in a slightly elliptical orbit. Because of this orbit, Earth's distance from the Sun varies slightly depending on where Earth is in its orbit. Contrary to popular opinion, however, Earth's seasons are only slightly related to this small variation in the planet's distance from the Sun. This is one of the most common misconceptions in astronomy. Mistakenly, people think that when Earth is farthest away from the Sun, it is winter; and when Earth is closest, summer occurs. The change in distance is, in fact, not great enough to cause any significant change in temperature. As a matter of fact, Earth is closest to the Sun in January, when it is winter in the Northern Hemisphere. Furthermore, if distance from the Sun determined the seasons, then all of Earth should have the same season at the same time. This is not the case. When it is summer in the Northern Hemisphere, it is winter in the Southern Hemisphere.

Instead, the reason Earth has seasons has to do with the angle at which Earth rotates as it revolves around the Sun. Generally, when objects rotate, they rotate around a vertical axis, just like a spinning top or a basketball spinning on someone's finger. Earth, however, rotates around an axis tilted relative to its orbit. The angle of the tilt is 23.5° from vertical (see figure 5).

Due to this tilt of Earth's rotation axis, some parts of Earth receive more vertical rays of sunlight and others receive more slanting rays. Slanting rays of sunlight are less intense and do not cause as much heating as more vertical rays of sunlight. In summer in the Northern Hemisphere, the north pole is tilted toward the Sun, as shown in figure 6. This arrangement allows for the more vertical rays of sunlight to strike the Northern



(Not to scale)

**FIGURE 5 Tilt of Earth's Rotational Axis**

In winter, the direction of tilt is the same as in summer, but since Earth is now on the opposite side of the Sun, the Southern Hemisphere is tilted toward the Sun and the Northern Hemisphere is tilted away (see figure 7). The rays that

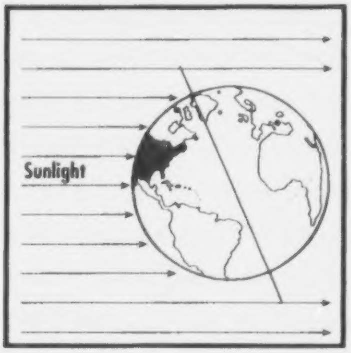


**FIGURE 6**
**Summer in the Northern Hemisphere**

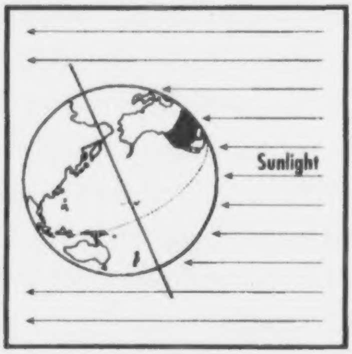


**FIGURE 7**
**Winter in the Northern Hemishpere**

strike the Northern Hemisphere are more slanting and do not cause as much heating. Fall and spring are simply the points between these two extremes.

Another consequence of having a tilted axis is that the day's length varies throughout the year. This further contributes to seasonal temperatures; the longer the day, the more energy received from the Sun to warm the atmosphere and the less time for that warmth to dissipate.

This explains seasonal temperature variations, but day-to-day changes are moderated by Earth's atmosphere. That is why the hottest and coldest days of the year rarely occur on the summer and winter solstices, respectively.

## Important Points for Students to Understand

- ◊ Earth's distance from the Sun has little to do with the seasons.
- ◊ The seasons are caused by Earth's axis of rotation being tilted 23.5° from the vertical with respect to its orbital plane.
- ◊ When a hemisphere is tilted toward the Sun, summer occurs, and when it is tilted away from the Sun, winter occurs there.
- ◊ Earth's orbit is only slightly elliptical; not nearly as elliptical as most people think.
- ◊ Slanting rays of sunlight do not heat the surface of Earth as much as vertical rays of sunlight.

## Time Management

This demonstration should take less than half a class period.

## Preparation

Misconceptions can be very hard to correct in students. One strategy for addressing misconceptions is making the students aware of their own ideas. This can be accomplished in the activity by having the students write out their understanding of why seasons occur before doing the activity. This serves three purposes. First, it gains the students' attention. Second, it makes them aware of their own beliefs. Finally, it provides a resource to help the teacher focus instruction on misconceptions that the students identify.

In this activity, one or two globes and a bright light are used to demonstrate why the seasons occur. Be sure that the light source is operable.

For further information, refer to Reading 12, "Reason for the Seasons."

## Suggestions for Further Study

Most textbooks depict Earth's orbit as much more elliptical than it actually is. Students could plot a scale model of Earth's true orbit to see that it more closely resembles a circle than an ellipse. This would enable them to see that distance is not a factor in the seasons. Include instructions on how to draw ellipses of varying eccentricity.

Students may also be interested in trying to devise a more graphic way of explaining the reason Earth has seasons. It would be informative for them to study other planets to learn if they have seasons.

## Suggestions for Interdisciplinary Reading and Study

Seasons are a common theme in music, literature, and art. Encourage students to find all kinds of music (classical, popular, folk) that have references to the seasons. The poem "Winter Moon" (at the beginning of Activity 11) by Langston Hughes provides a bridge from astronomy to meteorology. Ask the students what changes occur in the atmosphere from season to season to make the Moon appear different. In many locations, winter air is much less humid than at other times, making for a much sharper image of the Moon. The poem "Seasons" (at the beginning of this activity) by Evelyn Nitso provides a description of each season.

## Answers to Questions for Students

1. The light should have been brighter on the United States on the globe that had the United States tilted toward the Sun. In the diagram for the procedure section for this activity, this would be the globe on the right.
2. When the United States is tilted away from the light (the Sun), it receives more slanting rays of sunlight, and the light is therefore not as intense.
3. As the globe was walked around the light, the students should have observed a cycle of increasing and then decreasing intensity depending on where the globe was originally positioned in the orbit.
4. Winter and summer occur on opposite sides of the light when the intensity of light on the United States is the dimmest and brightest respectively. Fall and spring occur on opposite sides of the light halfway between winter and summer.
5. Somewhere in the Southern Hemisphere. Chile, for example.
6. Yes. For example, winter in the northeastern part of the United States is much longer and colder than in the southeast. This is because the farther north and south from the equator, the shorter the winter days are.
7. Depends on the present season. Generally, it would be the opposite of what the season is in the United States. If it is spring in the United States, it would be fall in Australia. This is because Australia is in the Southern Hemisphere and the United States is in the Northern Hemisphere.
8. They would have to have a tilt in their axes of rotation just as Earth has. It would not have to be a 23.5° tilt, however.

## Winter Moon

How thin and sharp is the moon tonight!
How thin and sharp and ghostly white
Is the slim curved crook of the moon tonight!

*Langston Hughes*

BEST COPY AVAILABLE

# Ping-Pong Phases

## Background

Every 29.5 days the Moon goes through a predictable cycle of changes in its shape which we call **phases**. For thousands of years, people have recorded these phases and during this time, the cycle has never changed. Even though it is known with great accuracy what the Moon will look like on any night of the year, many people cannot explain why the Moon's shape appears to change. Some people say that Earth's shadow falls on the Moon and blocks our view of part of it, as shown in figure 1. Others say that clouds block part of the Moon. Both explanations are incorrect.

Actually, the physical shape of the Moon never changes. It is always a sphere with millions of craters and other landforms on it. What changes is the portion of the Moon that can be seen from Earth. Half of the Moon is always illuminated by the Sun. Sometimes, the entire illuminated part of the Moon can be seen from Earth; this is called a full Moon. Other times, none of the illuminated part can be seen—a new Moon. And all the stages in between a new and full Moon occur as well. But why does the shape of the Moon appear to change in this way? It is because the Moon is in orbit around Earth.

This activity will show how the Moon's orbit causes the Moon's phases.

### Objective

The objective of this activity is to understand the cause of the Moon's phases.

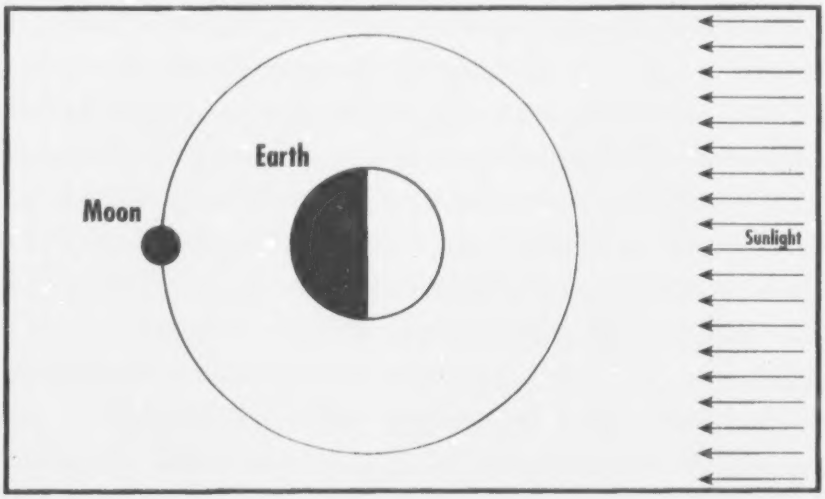
### Materials for Part 1

- ◊ 1 bright lamp (at least 75-watt) without shade
- ◊ 1 extension cord
- ◊ 1 Ping-Pong ball for each student (An option is polystyrene balls, one source of which is Molecular Model Enterprises, 116 Swift Street, Edgerton, WI 53334.)

### Materials for Part 2

For each pair of students:

- ◊ cardboard
- ◊ 15-cm diameter Styrofoam ball
- ◊ pencil
- ◊ black paint suitable for Styrofoam



(Not to scale)

FIGURE 1

## Part I Procedure

1. Place the bright lamp without a lamp shade in the center of a darkened room. *Make the room as dark as possible.*
2. Each student should have a Ping-Pong ball (a Moon), and the entire class should form a circle around the lamp. This circle should be as tight as possible but still allow each student to turn around with one arm extended. (Two circles, each with their own lamp, would work better if there are more than 15 students in the class.)
3. Everyone should face the lamp (the Sun) and hold the ball directly in front of his or her body and slightly above his or her head.
4. Observe what portion of the side of the "Moon" facing you is illuminated by the "Sun."
5. Now turn 45° to the left and make the same observation.
6. Continue to make 45° turns until you are once again facing the "Sun."

SCLINKS. THE WORLD'S A CLICK AWAY

Topic: moon phases
Go to: *www.scilinks.org*
Code: PESA92

## Questions and Conclusions

1. How much of the illuminated part of the ball (Moon) could you see when you were facing the lamp (Sun)?
2. How much of the illuminated part of the Moon could you see after each turn?
3. Whether you could see it or not, how much of the ball's surface area was always illuminated?

## Part 2 Procedure

1. Paint exactly half of the Styrofoam ball black with paint. The simplest way to do this is to cut a hole the diameter of the ball in a piece of cardboard. Putting the ball in that hole before painting it will keep one side protected from the paint. This simulates the Moon with one side illuminated by the Sun and the other side facing away from the Sun, the "dark side" of the Moon. (The Moon is actually all about the same color.)
2. Stick a pencil about 5 cm into the Styrofoam ball as shown in figure 2.
3. Stand in an open space and have another student stand about 3 m away facing you and holding the ball at eye level so that *you* can see the *black* side only.
4. The student holding the "Moon" should walk around you in a circle, making sure not to turn the ball and to always face in the same direction; for example, always face the board. The student will have to walk backwards and sideways at times to do this.
5. At each of the eight positions indicated on the Data Sheet, draw the portion of the white part of the ball that you can see.
6. Switch places with the student helping you and repeat the activity.
7. Label your drawings on the Data Sheet with a name for each phase of the Moon.

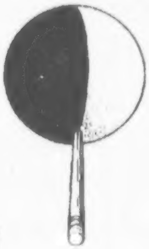
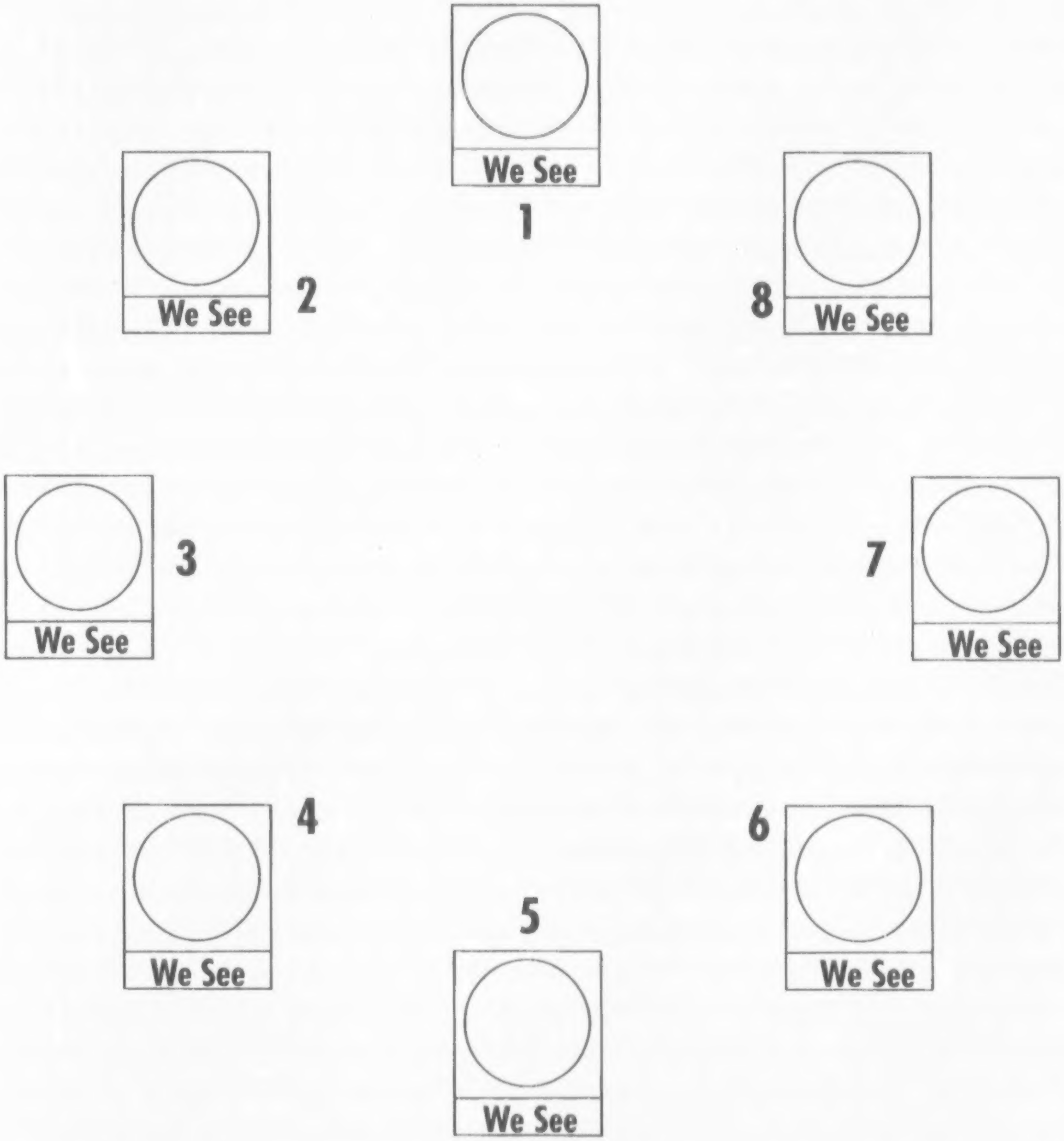


**FIGURE 2**

# Data Sheet



Keep this page upright as you draw what you see.

## Questions and Conclusions

4. What fraction of the ball was white (illuminated by the Sun) during the whole activity?
5. Were you able to see all the white or "illuminated" portion of the ball throughout the activity?
6. Describe what happened to the white portion of the ball that you could see as the Moon went around you in a circle.
7. If you represent Earth and the ball represents the Moon, describe where in the room the Sun would have been.

# Ping-Pong Phases

### Materials for Part 1

- ◊ 1 bright lamp (at least 75-watt) without shade
- ◊ 1 extension cord
- ◊ 1 Ping-Pong ball for each student (or polystyrene balls; see page 91)

### Materials for Part 2

For each pair of students:

- ◊ cardboard
- ◊ 15-cm diameter Styrofoam ball
- ◊ pencil
- ◊ black paint suitable for Styrofoam

### Vocabulary

**Phases of the Moon**: The cycle of changes of the portion of the Moon that is visible from Earth.

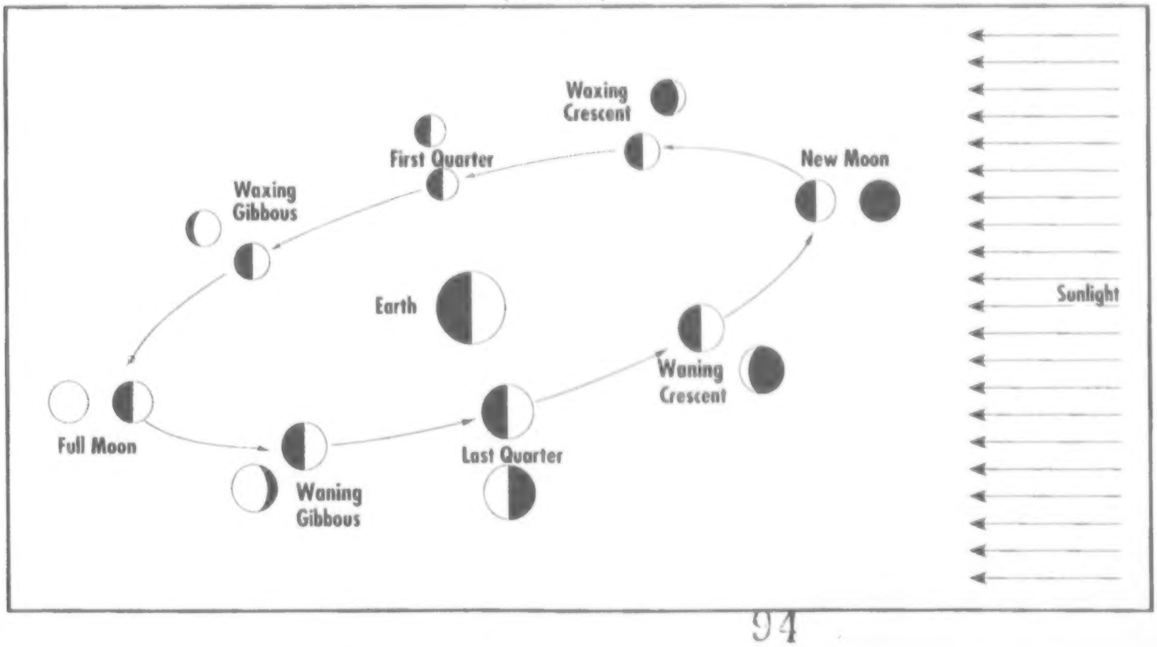
## What Is Happening?

Every 29.5 days, the Moon goes through a predictable cycle of changes. While most people are well aware of the Moon's phases, one of the most common misconceptions in astronomy concerns why these changes in its apparent shape occur. Perhaps the most prevalent, *incorrect* explanation for Moon phases is that they are caused by Earth's shadow on the Moon. (This is an eclipse.) Another incorrect explanation is that clouds block part of the Moon.

The *correct* explanation of the phases of the Moon involves visualizing the relationship among three separate objects, two of which are in motion around the third. Models work best to explain and to visualize this relationship. Figure 3 shows one model of how the Sun, Earth, and Moon interact to produce the phases of the Moon. In this model the Sun is positioned off the right-hand side of the page. The inner ring of Moons illustrates that half of the Moon is always illuminated—the half facing the Sun. However, depending on where the Moon is in its orbit around Earth, we may see all of the illuminated area, none of it, or any fraction between the two. The outer ring of Moons shows how the Moon would appear in each of eight positions to a person on Earth.

**FIGURE 3**

(Not to scale)



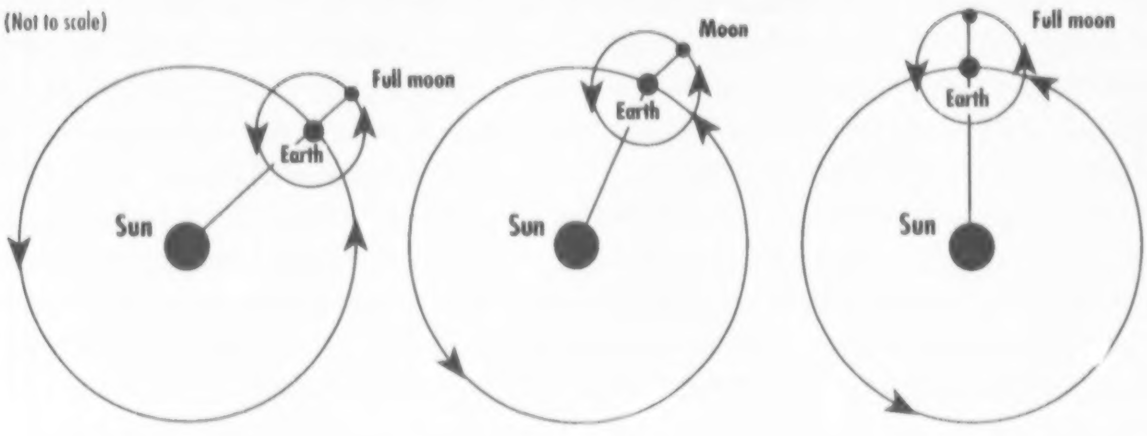
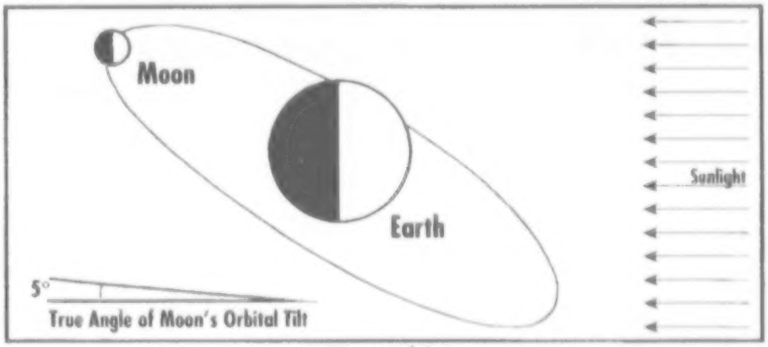


FIGURE 4a

FIGURE 4b

FIGURE 4c

This cycle of apparent shapes repeats every 29.5 days. This period of time may seem incorrect since it takes the Moon only 27.3 days to go around Earth once. The difference is explained by the fact that Earth is moving too. Figure 4a-c illustrates this. Figure 4a shows the alignment of the Sun, Moon, and Earth during the full Moon. After 27.3 days, the Moon has made one complete orbit around Earth, but Earth has moved in its own orbit too. Because of this, it takes about two more days before the Moon is back in a position relative to Earth to appear full. At that point, the cycle of phases begins again.



(Not to scale)

**FIGURE 5** **The Tilted Plane of the Moon's Orbit**

This activity is designed to show that the reason for the changes in the visible shape of the Moon is the motion of the Moon around Earth. Some students will probably question why an eclipse does not occur once a month when the Moon is on the opposite side of Earth from the Sun. The plane of the Moon's orbit is slightly tilted (as shown in figure 5), this tilt precludes a monthly eclipse from occurring. It is important to help students make the connection between what happens in this activity and reality. Questions like "Where are the Sun, Moon, and Earth when the Moon is in the first quarter?" require them to transfer their thinking from the model to reality.

The cause of phases of the Moon is one of the toughest concepts to visualize and understand. We have included two simulations for students in this activity to help you reinforce their thinking. Begin with Part 1 of this activity, then use Part 2 if you determine that some students are still clinging to naive conceptions.

## Important Points for Students to Understand

- Half of the Moon is always illuminated.
- The actual shape of the Moon does not change, only the portion of it that can be seen from Earth.
- The cycle of changes in the visible shape of the Moon is due to the Moon orbiting Earth.
- The changes in the apparent shape of the Moon occur in a predictable cycle which repeats every 29.5 days.
- The same side of the Moon always faces Earth, but the same side is not always illuminated because the Moon rotates.
- The plane of the Moon's orbit is slightly tilted, and this precludes a monthly eclipse.

## Time Management

Including set up, this activity should take one class period for each part.

## Preparations for Part I

The misconceptions that students have about the phases of the Moon can be very difficult to change. Simply presenting the correct explanation is often not enough. One strategy that may prove helpful is increasing students' awareness of their own ideas about phases. Prior to the activity, ask them to write their own explanations of why the shape of the Moon appears to change. Encourage them to use diagrams in their explanation. This exercise also serves the purpose of making the teacher aware of specific misconceptions that students may have. After completing the activity, you could return their original explanations for them to correct.

Prior to the class, be sure that there is one Ping-Pong ball for each student and that the lamp is in working order. It may be necessary to divide the class into two groups in order for them to stand close enough to the light and yet have enough room to rotate with one arm outstretched.

For further information, refer to Reading 13, "Phases of the Moon," and Reading 14, "Understanding the Moon Illusion."

## Preparation for Part 2

Painting the Styrofoam balls is a messy task, so you may want to do this for the students. Tempera or acrylic paint works best. Some spray paint dissolves Styrofoam. Only one class set needs to be prepared. They can then be used repeatedly.

Be sure beforehand that there is enough room for all students to work at once. It is helpful to mark off work spaces prior to the class. Students will work in pairs in this activity. You may want to pair students up prior to the class in order to save time.

It is important that students move the Styrofoam balls correctly when walking around the observer. One side of the Moon must always face in the same direction, toward a wall or the chalkboard, for example. The ball must *not* rotate. It is strongly suggested that you demonstrate the correct movement for the students. If done correctly, the larger size of the Styrofoam ball will allow students to understand how what they can see of the illuminated side of the Moon becomes the new, waxing, full, and waning Moon they see in the sky.

This activity may perpetuate some misconceptions that students already have about the Moon. You should point these out to the students and make it clear this activity is only a model which shows how a half-illuminated sphere may take on different appearances depending on the relative positions of the sphere and the observer. The students should be made to realize that this model is inaccurate in the following ways. First, the Moon is not varied in coloration as the Styrofoam ball is. Second, the same side of the Moon is not always illuminated. At different times in the cycle of phases, all parts of the Moon become illuminated. Finally, the Moon rotates as it orbits Earth whereas the Styrofoam ball in this activity does not. It is this rotation of the Moon that allows the same side of the Moon always to face Earth, and it allows all parts of the Moon to be illuminated at different times in the cycle.

## Suggestions for Further Study

Students can use these activities to dispel two common misconceptions about the Moon. It is commonly believed that the same side of the Moon is always illuminated since the same side always faces Earth. The first activity best demonstrates that this is not true. Another misconception many people have is that since the same side of the Moon always faces Earth, the Moon must not rotate. From the first activity students can see that even though the same side of the Ping-Pong ball always faces them, the ball is

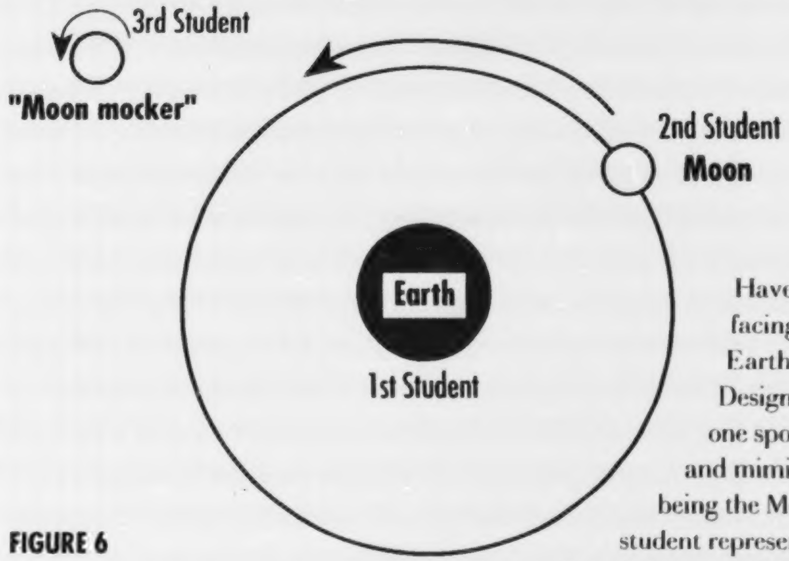


FIGURE 6

rotating nonetheless.

Care must be taken, if you choose Part 2, to not perpetuate these misconceptions.

Here is another short activity that may further help dispel these misconceptions. Have two students stand 2 m apart facing each other. One represents Earth and the other the Moon. Designate a third student to stand in one spot to the side of the other two and mimic the motion of the person being the Moon (see figure 6). Have the student representing the Moon walk side-step in a circle around the other student, facing him or her at all times. In this way, the same side of the student representing the Moon is always facing "Earth." As the "Moon" is going around "Earth," the third student stays in one spot but will have to turn his or her body in order to face the same way as the "Moon." This should demonstrate to students that even though the same side of the Moon always faces Earth, the Moon still rotates and hence the same side could not always be illuminated by the Sun.

Going beyond the concepts addressed directly, this activity is a good starting point for students to explore the difference between a lunar eclipse and a new Moon and to learn the names of the phases of the Moon. It is also an opportunity to discuss the moons of other planets.

## Suggestions for Interdisciplinary Reading and Study

Through the ages, the phases of the Moon and lunar eclipses have been a source of myth and folklore. It is only in the last few centuries that phases and eclipses have been correctly explained. (Actually, the ancient Greeks had phases and eclipses figured out, although they, of course, didn't think of the Earth moving but of the Sun and Moon orbiting Earth. The effect is the same—you still get phases and eclipses.) Different cultures have explained these phenomena in different ways. Comparing these cultures and their explanations would be an interesting interdisciplinary project.

The phases of the Moon have also found their way into poetry. Langston Hughes's "Winter Moon" (at the beginning of this activity) and Myra Cohn Livingston's "Moon" (at the beginning of Activity 1) are two examples. Students may have heard or read the phrase "blue Moon." Encourage them to find out what it means when someone says that something happens "once in a blue Moon." ("Blue Moon" refers to the occurrence of two full moons in the same calendar month, something that happens only once or twice a year.) Ask students to find specific references to the blue Moon in music and literature.

For many people, the Moon in all its phases is a thing of great beauty and wonder. As such, it has been the source of inspiration for art, literature, and music. Encourage students to listen for references to the Moon in their favorite music. Challenge them to find misconceptions about the Moon in these songs.

## Answers to Questions for Students

1. None or almost none. This is the new Moon.
2. 1st turn—25 percent of the illuminated portion of the Moon was visible, corresponding to the waxing crescent phase.

   2nd turn—50 percent—first quarter

   3rd turn—75 percent—waxing gibbous

   4th turn—100 percent—full Moon

   5th turn—75 percent—waning gibbous

   6th turn —50 percent—third quarter

   7th turn—25 percent—waning crescent

   8th turn—0 percent—new Moon
3. Fifty percent of the ball was always illuminated.
4. Half of the ball was white even though it could not all be seen all the time.
5. No.
6. Assuming the student started with the black side facing him or her, none of the white would have been seen initially. As the Moon moved, a crescent would have first appeared, then a half, then three quarters, then a full Moon. As the Moon continued to move, this pattern would have reversed until only the black side was visible again.
7. This will vary for each student. The Sun should be in a position to illuminate the white half of the ball.

# Introduction

The following readings elaborate on the concepts presented in the preceding activities. They include essays written especially for this volume, scientific articles, excerpts from other teacher materials, and excerpts from publications written by NASA. While these readings were written and selected with the teacher in mind, students should be encouraged to read them for interest and for additional study.

# Angular Diameters

Measuring diameters of objects in the Solar System presents just as big a problem as measuring distances. Since we cannot measure the size directly, we use a technique that measures the **angular diameter**.

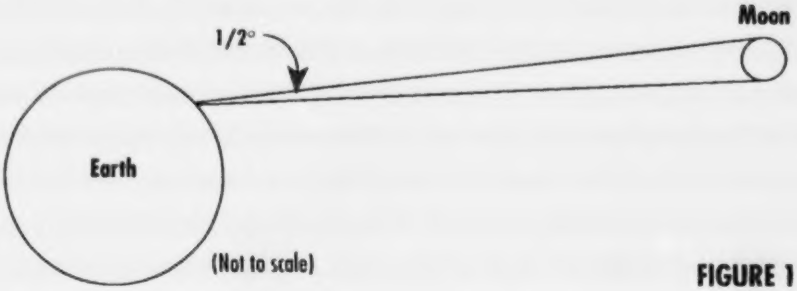


FIGURE 1

Figure 1 shows an example of an angular diameter. If you could take one piece of string and stretch it from where you are all the way to the right side of the Moon, and then stretch another piece of string to the left side of the Moon from the same starting point, the angle between those two pieces of string would be $^1/_2{}^\circ$.

It is possible for two objects to have the same angular diameter even if they are not the same size. Hold your thumb in front of one eye while closing the other. Move your thumb closer to your eye or farther away until it just blocks your view of someone else's head. You know that your thumb is not as big as the person's head, so how can your thumb block the view? The reason is that both your thumb and the person's head have the same angular diameter at that point where one blocks the other, even though they are not the same size. When two objects have the same angular diameter, they have the same *apparent size*; that is, they *appear* to be the same size. You will also notice that when your thumb is closer to your eyes, it appears larger than at arm's length.

The apparent size of an object relates to how close or far away it is. Take a coin and place it on a piece of paper. Make a pencil dot seven centimeters to the left of the coin. Draw two lines that go from the dot to either side of the coin as shown in figure 2.

Now move the coin about a centimeter to the right and draw the two lines again from the same point. Move the coin further to the right and draw the lines. Notice that as the coin is moved farther away, the angle gets smaller. If you viewed the coin from the dot, the apparent size would continually decrease.

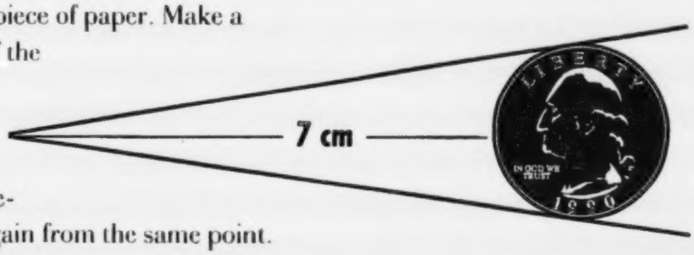


FIGURE 2

Angular diameters are only useful if the distance to the object is known. An object's true diameter can be calculated from its distance and its angular diameter by two different methods. One method involves using an equation from geometry—$s = r(q/57)$ where:

$s$ = true diameter of the object
$r$ = distance to the object (must be in same unit as "s")
$q$ = angular diameter of the object in degrees
57 = conversion factor of radians to degrees

This is true for small angles. Unfortunately, the angular diameter of most objects of interest in astronomy, including planets, is $^{1}/_{2}{}^{\circ}$ or less, and such angles are hard to measure with commonly available equipment. The second method does not require expensive equipment but does require knowledge of similar triangles.

The relevant features of similar triangles can be illustrated with the following exercise. Using a protractor, draw two lines on a piece of paper to make an acute angle (the angle in figure 3 is 53°). On one line, start at the point of intersection and make a mark every 3 cm for 12 cm. On the other line, start at the same point and make a dot every 5 cm for 15 cm. Connect the dots as shown in figure 3. You have now made a series of triangles that all have one angle in common, angle X. In this diagram, angle X is 53°. Measure angles A, B, and C in your drawing using a protractor. Are they the same? Measure angles D, E, and F. Are they the same? When all the corresponding angles are equal like this, then the triangles are similar. Similar triangles have another interesting feature. Measure lines XD and XE and divide the first by the second. Now measure lines DA and EB and divide the first by the second. You should get the same, or nearly the same, answer for both. This feature of similar triangles is essential in using angular diameters to determine true diameters of planets in the Solar System.

**FIGURE 3**

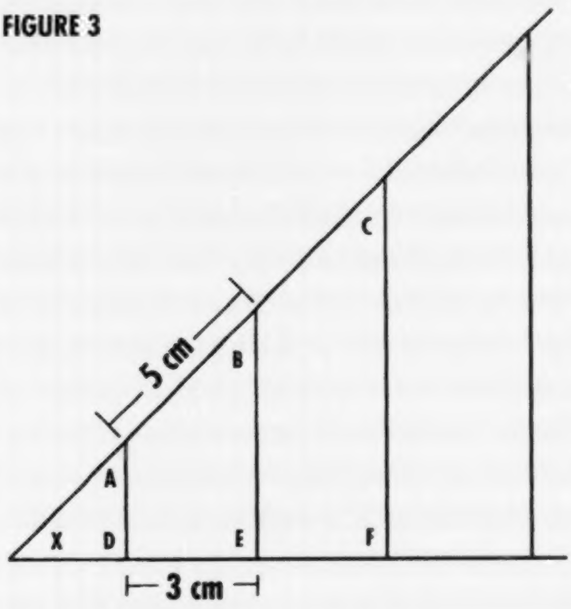


Figure 4 shows how a dime and the principles of similar triangles can be used to calculate the diameter of the Moon. Once the dime is moved to a point where it just blocks out the view of the full Moon, the two have the same angular diameter. Since

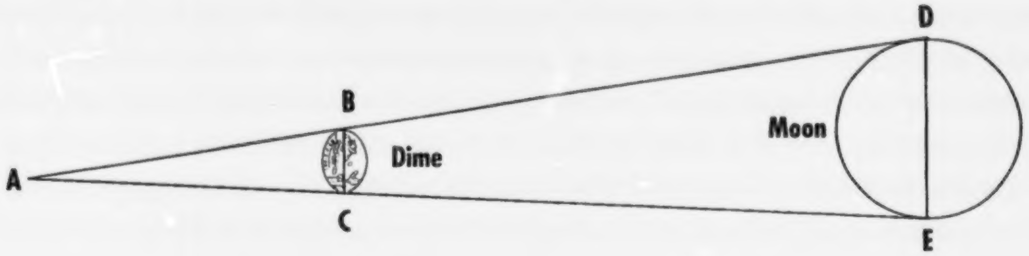


FIGURE 4

they have the same angular diameter, two similar triangles exist, ABC and ADE. The distance to the dime (AB) and its diameter (BC) are easily measured. The distance to the Moon (AD) is known from past measurements. Therefore the diameter of the Moon (DE) can be calculated by solving the ratio AB/AD = BC/DE for DE. Again, this is possible because of the similar triangles which exist when the two objects have the same angular diameter.

# What Is a Light Year?

The fact that Earth is the only habitable planet in this Solar System is well established. There are, however, innumerable other stars besides the Sun, and, in the last decade, astronomers have discovered dozens of planets orbiting other stars. (You can stay up-to-date on extrasolar planets—although some of them may not be confirmed yet—at *cfa-www.harvard.edu/planets*. As of May 2001, the existence of 60 extrasolar planets has been confirmed.)

The distances to these stars are immense. Their light takes many years to reach us here on Earth. These stars are being studied now, and one of the fundamental facts to be determined is their distance from the Sun. Typical units such as miles and kilometers are awkward to measure such distances; therefore, a unit known as the **light year** is used.

Which number is easier to understand and work with: 5,840 days or 16 years? Both represent the same amount of time. Most people would choose 16 years because smaller numbers are easier to understand. Distances in the Universe are more difficult to comprehend or imagine when they are measured in units such as kilometers or miles. This led scientists to develop a new unit of measurement which makes the astronomical distances more manageable—the light year.

The concept of a light year is sometimes difficult to understand partly because of the words themselves. The term "light year" uses what is normally thought of as a time unit, the year, to measure a distance. But time units are often used to talk about distances. People often talk about how far it is to some destination by describing how *long* it takes to get there. As an example, it takes about four hours to fly from the East Coast to the West Coast. Although a time unit is being used, distance is actually being represented.

A light year is defined as the distance that light travels in one Earth year. Light moves extremely fast, 300 thousand km/s. In one second light can travel around Earth almost four times. Nothing travels faster; light is the speed limit. In 31 million seconds—or one year—light will travel a distance of 9.46 trillion kilometers, or 240 million times around Earth. This distance equals one light year, abbreviated "ly."

Distances in the universe are so large that it helps to express them in the scale of light years. Consider the distance to the star Sirius—almost 85 trillion kilometers. That is a huge number to comprehend. Using the light year as the unit of measurement, the distance becomes only 9 ly, much easier to work with. The light year is an appropriate unit to measure vast distances.

The speed of light makes everything appear to happen instantly in our everyday experience. When we watch a soccer game and see someone kick the ball, we assume that the ball was kicked right then, not five minutes before we saw it. For all practical purposes, we are safe in that assumption because light travels so fast. In order for us to see the soccer ball, we must see the light that is being reflected from it, and it does take time for the light to travel from the ball to our eyes. However, the amount of time is far too short to measure. If the distance from the ball to our eyes were 10 m, the light reflecting off the ball would take only 300 millionths of a second to reach our eyes.

Stars are millions and millions of kilometers away. To see a star, that star's light must travel across space to our eyes. The time required for light to travel such a huge distance is easily measured. If the star is 5 ly away, then the light we are seeing from that star took five years to travel to our eyes. It also means that what we see happening at that star is actually what happened five years ago, not what is happening in the star's present. If we see a flare from the star's surface, we are seeing an event that happened five years ago.

Imagine that there is a planet with people on it that is 60 ly away from Earth. These people have an extremely powerful telescope and can actually make out the details of what is happening on Earth. If they aim their telescope at Europe, they will see World War II being fought since it was happening 60 years ago. They will not see the events of 2002 on Earth until the year 2062.

This presents a challenge for the astronomers who study stars. They can never see what is going on in a star's present, only its past. In a sense they are detectives trying to solve a crime without all the clues, and what evidence they do have is years out of date.

# Hubble Space Telescope

All our knowledge about the Universe is a result of what we observe; yet with the naked eye, we can see only about 6,000 of the hundred billion stars in our own galaxy, the Milky Way. Our largest ground-based telescopes have extended our vision to reveal a universe with an estimated hundred billion galaxies, each populated by several hundred billion stars.

Radiation in the form of light brings us the information needed to understand the past. Light travels fast, but space is so vast that much time passes before the light from distant objects reaches us. When it is collected by the Hubble Space Telescope this information will tell us about the conditions which prevailed at the source when the light was emitted. So in effect, we are "looking back in time."

**Topic: Hubble Space Telescope**
**Go to: *www.scilinks.org***
**Code: PESA108**

The Hubble Space Telescope is the largest astronomical observatory ever placed in orbit. The telescope is in orbit 595 kilometers above Earth, and unlike most observatories, is outside our atmosphere. From orbit, the telescope can detect light before it is absorbed or distorted by the atmosphere. It can "see" stars that release infrared and ultraviolet light that, because of the atmosphere, never reaches telescopes on Earth. The 11,300 kg observatory is about the size of a bus and looks like a tower of stacked silver cannisters. The Hubble Space Telescope uses five instruments to study the Universe: two cameras, two spectrographs, and one photometer.

The two cameras record light that is translated into pictures of the Universe. The spectrographs are used to separate radiation by energy. By studying the intensity and distribution of radiation, scientists can determine an object's chemistry, temperature, and density. The photometer records the total light from an object in space and notes any changes in brightness in fractions of a second. Astronomers use the data to determine the relation of stars to each other and their distances from Earth. The Hubble Space Telescope is attempting to answer key questions in astronomy and astrophysics: How do stars and galaxies form and evolve? How big is the Universe? What are quasars and other exotic objects? Do other planets exist?

Reprinted courtesy of NASA.

# Scale Measurements

Using parallax and angular diameters are two ways of measuring the distance to and size of objects in the Solar System. The **scale model** is another method of indirect measurement used in astronomy and other Earth sciences as well.

Everyone has seen a model of something: cars, airplanes, buildings, and spacecraft, for example. You can use these models to determine what the measurements would be on the real thing. As long as the measurement of any one part of the real object is known, the rest of the measurements can be determined from the model.

For example, suppose the tire on a scale model car has a diameter of 2 cm, and on the real car the tire measures 60 cm in diameter. This means that 2 cm on the model represents 60 cm on the real car (or, dividing each measurement by 2, then 1 cm on the model represents 30 cm on the real car). This is all that is required to determine all the measurements on the real car from the model. If the model is 20 cm long, then the car must be 20 × 30 or 600 cm long. If the model is 7.5 cm wide, how wide is the car? If the model is 2.5 cm high, how high is the car?

The same technique can be applied to the Solar System. If a scale model is drawn on a piece of paper, then only one true distance must be found in order to calculate all the others. Johannes Kepler, a German astronomer and mathematician, built a scale model of the Solar System more than 300 years ago.

Each of these methods—parallax, angular diameters, and scale models—is used to determine where Earth is in the Solar System, where the other planets are, and the size of each object. Such information is essential to grasp the significance of the unique aspects of Earth.

If Earth were much closer to the Sun, its oceans—the birthplace of life—would have boiled away long ago. Earth is the only planet in the Solar System with liquid oceans. The plants that came into existence because of the oceans, and the oceans themselves, moderate the amount of carbon dioxide in the atmosphere. Without these, Earth would have developed a runaway greenhouse effect (a topic discussed in greater detail later) increasing the average temperature to hundreds of degrees Celsius. In this sense, it would have been similar to Venus, which is devoid of life.

If Earth had been farther from the Sun, all the water that is in the oceans now would have been frozen, again depriving it of one of the necessities for life, liquid water. Had this happened, Earth would have resembled Mars more closely, another planet found to have no life.

The facts of Earth's location and size are the beginning points to understanding what makes Earth unique and why it is the only planet in the Solar System that sustains life. These facts only become apparent when Earth is placed in the context of the rest of the Solar System. The comparisons which then arise between Earth and the other planets lead to a greater appreciation of our place in the Solar System and Universe.

# Scouting Earth/Moon

. . . Soon they [Centaurian explorers] would perceive that the double planet was a fairly small planet attended by an unusually large satellite. Their instruments would reveal the Moon to be an airless, waterless world, its axial rotation captured by its primary, its surface temperatures spanning the range from 240° F to –200° F, its tortured surface preserving the scars of uncounted past events. The planet Earth, in contrast, would seem a beautiful, bright colored sphere. It would be partly veiled by whorls and streaks of white gases in its otherwise semitransparent atmosphere. The colors of the planet would be blue, white, brown, dark green, and russet red. Sometimes, excitingly, a unique bright-silver glitter would shine from the surface.

Instrumental analysis would show that Earth's atmosphere is a combination of nitrogen and oxygen, lightly spiced with carbon dioxide, argon, and trace elements. It is thick enough to serve as a global heat-transfer mechanism and as a shield against lethal energetic particles and bits of rocky solar-system debris racing in at hypersonic velocities. But for all its complex and everchanging white turbulence, the atmosphere would also be frequently semitransparent, giving the planet a window on the universe.

Excerpt reprinted from *This Island Earth,* ed. Oran W. Hicks, (Washington, D.C.: Scientific and Technical Information Division, Office of Technology Utilization, NASA, 1970) p 14, courtesy of NASA.

# The Parallax Effect

There are two ways to measure distance, directly and indirectly. When we use a tape measure or a meter stick and measure a distance, we are making a direct measurement. If we look at two chairs across the room, compare their relative sizes, and then infer which chair is closer, we are measuring indirectly. Now consider distances on a much larger scale—like those of the Solar System. Imagine being faced with the task of using ordinary rulers and scales to measure the circumference of Earth or the distance from Earth to Venus. To find out how big the other planets are and how far away they are, we must use forms of indirect measurement. Three common methods are scale measurement, measurement by parallax, and angular diameter.

One of the methods of indirect measurement takes advantage of the **parallax effect**. To demonstrate this phenomenon, hold a pencil in front of you at arm's length and look at it with one eye. Line it up with something in the background, a clock on the wall or a tree. Without moving the pencil or your head, look at it with your other eye. Notice that the pencil appears to have moved against the background (see figure 1). This apparent change of position against background objects when viewed from different points of observation is called the parallax effect. Each of our eyes is a different point of observation; therefore, we experience a parallax.

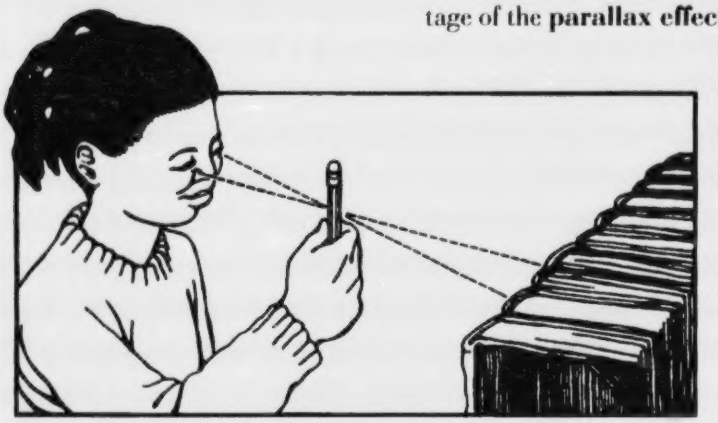
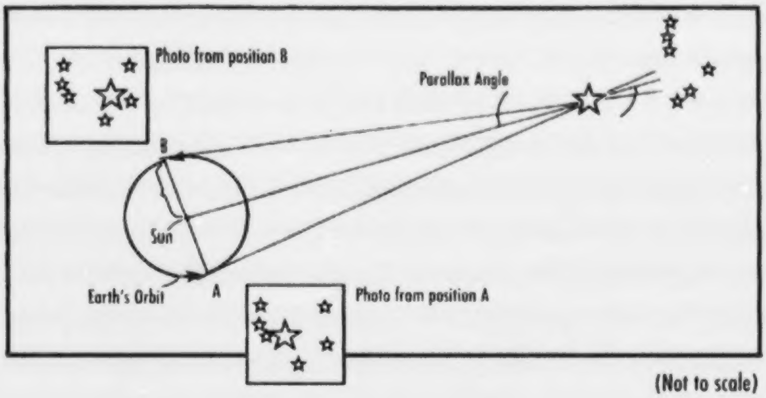


**FIGURE 1**

Several factors affect parallax. Two major factors are the distance between the observer and the object being observed, and the distance between the two points of observation, called the baseline. The baseline must be known if parallax is to provide a useful measurement of distance. In the example above, the baseline was the distance between your two eyes. The fact that there is a distance between our eyes makes it possible to judge distance by parallax. Our depth perception is dramatically reduced when we use only one eye. A criterion for accurately judging distance by parallax, though, is that the observer must be so far away from the *background* objects that there is no measurable parallax effect for them.



(Not to scale)

**FIGURE 2**

The baseline and the distance to the object affect parallax in opposite ways. As the baseline increases, parallax increases and is more useful for measuring distances. For this reason, larger baselines are always desired. As the distance to the object increases, the parallax *decreases*. Therefore, the farther away an object is, the more difficult it is to measure its parallax and the greater the need to have a large baseline. This phenomena explains why stars all look equidistant to the naked eye.

To measure the distance to some of the closest stars, the required baseline is the diameter of Earth's orbit around the Sun (149,000,000 km), hence the period between the two observations is six months (see figure 2). The actual calculation of the distance to a star uses the *parallax angle* which is one half of the apparent change in its angular position.

BEST COPY AVAILABLE

# Understanding the Earth as a System

We live on a planet of extraordinary complexity; the presence of an atmosphere and oceans with the right chemical composition on a solid planet has supported the development of an abundant diversity of life. Throughout geologic history, the atmosphere, oceans, and land have interacted to produce global environmental change to which life has contributed and adapted. Today, one species of life, humankind, through increasing population and quest for improved quality of human life, has developed the capability of changing our global environment in ways that we are only beginning to perceive, but do not fully understand.

In some cases, such as the depletion of Earth's energy and mineral resources, the effects of human activity are obvious. In other cases, such as the alteration of atmospheric chemical composition, the processes of change are difficult to document, and their consequences harder to foresee. Moreover, the effects of many human-induced changes cannot readily be distinguished from the results of natural change over time periods of decades to centuries.

We know that we have embarked on a global experiment, but we do not know the consequences. Model predictions suggest that the Earth should be warming in response to increasing carbon dioxide and other gases in the atmosphere, but observations are ambiguous. Is the signal lost in the noise of natural climate variability, or are there other processes at work? Until we more completely understand the Earth system, we will not be able to answer such critical questions.

The oceans, atmosphere, and ice-covered regions of the globe are now recognized to be closely coupled in shaping Earth's weather and climate. Both terrestrial and oceanic biota are recognized as exerting a major influence on global climate and the chemical cycles important to life. But the fundamental questions about how the Earth system works remain unanswered.

Over the past 40 years, our view of the solid Earth has been dramatically transformed. The earlier notion of a placid, static globe has been replaced by the dynamism of plate tectonics. Patterns of mountain-building, volcanism, and earthquake activity all fit consistently into this new view.

It is essential that we understand how components of this system interact—from the short time scales of weather systems to millennia of geological time—and how we affect these interactions. Until we have that understanding, we will not be able to predict how human activities will change the environment.

Reprinted from the brochure *EOS: A Mission to Planet Earth* (Washington, D.C.: NASA, 1990) p 3, courtesy of NASA.

# After the Warming

Throughout history, the Earth has experienced periods of warming and cooling. Great Ice Ages have alternated with warmer periods, flooding coastlines, perpetuating deserts, and annihilating entire ecosystems. Over the course of human history, rising and falling temperatures have influenced the flourishing or perishing of civilizations. During the Little Ice Age (1500–1850), for example, when temperatures averaged only a few tenths of a degree Celsius cooler than today, Europe documented numerous years of famine and plague. Today, global warming, the rising of the Earth's average temperature, is seen by some scientists as a very real possibility—not millions of years from now but as early as 2050. These scientists are predicting that by that date, a global warming of between 1.5 and 4.5 degrees Celsius (C) will occur. To put these temperatures in perspective, consider that during the 10,000-year era of human civilization, the Earth's average temperature has not been warmer by more than 1 to 2 degrees Celsius than it is today.

An increase of this amount could have devastating effects on some areas of the planet. Melting ice caps and glaciers might cause sea levels to rise, while increased heat might cause severe droughts to occur. For each 1° Celsius of global warming, a 160 kilometer shift poleward in temperature zones may occur. The repercussions from these environmental changes would have profound impact on agriculture, animal husbandry, forestry, recreation, industry, and many other human activities. The phenomenon that is responsible for producing a change in the Earth's temperature is known as the greenhouse effect.

## What is the Greenhouse Effect?

The greenhouse effect is the process by which the Earth is warmed by the Sun. Energy from sunlight warms the Earth's surface. Some of this energy is absorbed by the surface, and some is re-radiated into space. Certain gases in the atmosphere trap some of this energy which continues to heat the atmosphere. These greenhouse gases, principally water vapor (which is concentrated near the Earth's surface), carbon dioxide ($CO_2$), and methane, absorb heat and warm the planet to maintain an average global temperature of 15°C. If not for this warming process, the Earth would be uninhabitable, a virtual frozen wasteland at -15°C.

The greenhouse gases carbon dioxide and methane are released naturally by volcanoes, oceans, plants, and animals. But human industry and agriculture also account for significant production, as well as for two other greenhouse gases, nitrous oxide and chlorofluorocarbons. Carbon dioxide is produced from the combustion of fossil fuels such as coal and oil, and from deforestation by the burning of trees and brush cleared from land. Methane is released from crops, livestock, and garbage. Nitrous oxide is emitted by industry and fertilizers. Chlorofluorocarbons, or CFC's, come from aerosol spray cans, air conditioners, refrigerators, plastic foam, and solvents. The accretion of these and other greenhouse gases into the atmosphere through human activity has caused their concentrations to greatly increase since the beginning of the Industrial Revolution (1750–1914).

Many scientists worry that continued greenhouse gas increases with correspondingly higher temperatures will threaten the future of life on the planet. However, there could be some potential gains from increased levels of carbon dioxide, including an increase in plant growth and the warming of marginally productive northern regions which could enhance their habitation and stimulate growth of vegetation. Regardless of the impact, most scientist agree on one thing—that global warming will occur. The only questions that remain are "how much?" and "how soon?"

Climatic change refers to long shifts (decades in length) in normal climate. While there have been occasional variations in climate such as heat waves and cold spells, these are considered temporary occurrences, not true climatic changes. When the 1980s recorded four years of the warmest temperatures within the past 110 years, some scientists claimed that this marked the beginning of a period of climatic change; others claimed that it was too soon to tell.

Research conducted by Wallace S. Broecker, professor of geochemistry at Lamont-Doherty Geological Observatory at Columbia University, has been led to an interesting hypothesis regarding how fast climatic change may occur. From his studies of records of pollen grains buried in Greenland ice cap samples, Broecker theorized that climatic change may occur so suddenly and dramatically that people would have no opportunity to anticipate it or adapt to it. Broecker cites a period approximately 10,000 years ago when climate change occurred within a period of one century. Known as the Younger Dryas, this period occurred as a mini-ice age in northwestern Europe, Greenland, and maritime Canada.

The occurrence of any long-term climatic change involves complex natural processes. The greenhouse effect is but one of those processes. Others, like variations in the carbon cycle and oceanic circulation, along with overlapping cycles in the Earth's orbit, tilt, and wobble (Milankovich cycles), combine to affect global climatic changes.

## The Role of the Carbon Cycle

As a greenhouse gas, carbon dioxide makes up only .03 percent of the atmosphere's dry weight. Yet it is an essential ingredient for maintaining life on Earth. During the carbon cycle, green plants absorb carbon dioxide from the air. In return, oxygen is given off as a waste product and inhaled by animals and humans. Springtime is the period of greatest plant growth and carbon dioxide absorption. In the autumn, carbon dioxide is released into the atmosphere as leaves fall and decompose. In addition to land plants, microscopic ocean plants called phytoplankton are also responsible for absorbing carbon and releasing oxygen. For millions of years, the carbon cycle has helped to regulate the amount of carbon dioxide in the atmosphere. Unfortunately, given the rate at which carbon dioxide is presently being released and the rate of reduction in green plants due to deforestation, the right balance of carbon dioxide in the atmosphere that is needed to help maintain the present global average temperature is becoming more difficult to maintain.

**Topic: carbon cycle**
**Go to: *www.scilinks.org***
**Code: PESA118**

## Oceanic Circulation

The oceans maintain a pattern of circulation in which the flow of a deep current of salty water empties from the Pacific into the Atlantic. This is due in part to the nature of water evaporation in the North Atlantic. Surface waters in this region are warmer than those of the North Pacific. Warmer waters will evaporate more, leaving greater amounts of salt to flow through the sea from the Atlantic to the Pacific. It is hypothesized that any alterations in salt distribution caused by the transport of water vapor through the atmosphere from one ocean basin to another will affect climate change. Past climate records taken from ice and sediment cores indicate that climate changes have indeed occurred because of such reorganizations. It is hypothesized that an increase in the atmosphere's greenhouse gases may force yet another reorganization.

## The Milankovich Cycles

These cycles refer to the studies of Yugoslavian scientist, Milutin Milankovich (1930), regarding the influence that changes in the Earth's orbit have on glaciation. Three specific aspects of the Earth's orbit comprise the Milankovich cycles: over 100,000 years the Earth's orbit changes shape; over 41,000 years the Earth's tilt on its axis changes; and over 19,000 years the Earth has a wobble cycle.

## Researching the Issue

Before the turn of the century, some scientists expressed concern about the extent to which fossil fuel emissions could alter the composition of the Earth's atmosphere. In 1896, Swedish chemist Svante Arrhennius predicted that if carbon dioxide doubled, the Earth's surface would warm by approximately 5° Celsius. Many scientists today concur with that forecast. In 1958, David Keeling and Roger Revelle of the Scripps Institute of Oceanography in La Jolla, California began to record the atmosphere's concentration of carbon dioxide on the summit of Mauna Loa in Hawaii. Regular measurements of carbon dioxide taken since that time have indicated a steady rise in this greenhouse gas from 315 ppm (parts per million) thirty years ago to 351 ppm in 1988. These increases in carbon dioxide concentration have been contributed by human activities. Using the records at Mauna Loa, along with evidence from tree rings (which can depict periods of warming and cooling) and an analysis of air bubbles trapped in polar and glacial ice, scientists have estimated the preindustrial carbon dioxide level to be around 280 ppm. These statistics indicate that human activity has increased the level of carbon dioxide by approximately 25% since the start of the Industrial Revolution (c. 1750).

An important research tool for modern scientists is the use of computer climate-change models of the global system. Powerful computers can examine interrelationships among many climatic features and mathematically factor in "what-if" scenarios. Given a set of climatic change variables, these computers output models which represents how the planet might look based on the provided data. Such modeling is extremely complex, requiring the adequate representation of feedbacks. Feedbacks are atmospheric and environmental conditions that may have an effect on global warming. In computer modeling, positive feedbacks may hasten the process while negative feedbacks may slow it down.

Examples of feedbacks are the effect that types of clouds, their altitude and brightness have on global warming, the effect that sunlight has on melting ice and snow, and the natural circulation of oceans, the rate at which plants and animals utilize carbon dioxide, and how and where carbon dioxide is deposited in sediments.

## Debating the Issue

For the past several years, public concern—and scientific controversy—about the greenhouse effect have been growing. Throughout the 1980s, reputable scientists from all over the world have predicted numerous scenarios, many doomsday in their projections. These predictions are based on steadily increasing measurements of carbon dioxide and other greenhouse gases in the atmosphere, coupled with the increase in population, factories, and farms since about 1800. Many scientists and policy makers alike are deeply concerned about the continued increase of these gases, especially as nations like China and India take further steps towards industrialization.

Other equally reputable scientists have angrily disputed the doomsday predictions, likening the threat of world-wide devastation to a "Chicken Little" scenario. These scientists claim that despite the extensive research to date, too many uncertainties remain regarding the potential for global warming. One of their major concerns is with the use of computer models as definitive evidence of a global warming threat. Their position is that, at present, there is no accurate way to incorporate the effects of atmospheric and oceanic feedbacks into the computer models.

Many climatologists predict that the greatest warming will occur at higher latitudes in the winter. According to computer models, areas within these latitudes are expected to be at least twice the global average temperature increase. However, according to Patrick J. Michaels, associate professor of environmental science with the University of Virginia, there has been no significant warming in the Northern Hemisphere since 1930. In fact, Michaels points out that although carbon dioxide measurements have been increasing, there is little evidence of any average temperature warming.

Tom Karl, a scientist with the National Oceanic and Atmospheric Agency (NOAA), claims that the National Aeronautic and Space Administration's twentieth-century U.S. temperature data, used in congressional testimony on global warming, are warm-measurement biased. He maintains that NASA's measurements over the United States warmed up nearly a degree during this century not due to the greenhouse effect, but rather, to what he calls "artificial" warming, i.e., the trend for cities to grow up around NOAA's weather stations.

While the debate among scientists continues, the public and policy makers are asking a major question, "Can we afford to wait for absolute certainty regarding the timing and extent of the environmental impact of global warming?" Just as the calls for further research continue to be expressed, so do the calls for immediate action.

Reprinted from *After the Warming Teacher's Guide* (Maryland State Department of Education, ©1990) p 8–10, by permission of the publisher.

# Atmosphere, Oceans, Cryosphere, and Hydrologic Cycle

The Earth is unique in possessing an ocean and living organisms. There are growing realizations that the hydrosphere and biosphere, while constituting tiny fractions of the planet's mass, are crucial in establishing the character of the Earth in several ways.

The ocean, to a visitor from another planet interested in physics, would be most quickly recognized as the controller of water and heat, and the relative sluggishness of its circulation makes it the buffer to the variation of the atmosphere on time scales ranging from days to seasons. It also imposes its own pattern on decadal and longer time scales, as manifest in such phenomena as El Nino. The ocean and the cryosphere also are the main control on solar inputs to climate and weather. On longer time scales—$10^2$ to $10^6$ years—the ocean, glaciers, and their distribution with respect to the land vie with volcanic inputs and solar variations in influencing climate. The relative roles of these different effects are still ill-understood; many observations remain that could improve our insight into these phenomena that are so important to human welfare.

SCILINKS.
THE WORLD'S A CLICK AWAY

**Topic: water cycle**
**Go to: *www.scilinks.org***
**Code: PESA122**

It would be evident to a visitor interested in biology that the ocean would be essential to the development of life. Its margins have offered such stable riches as light, nutrients, perches, and protection from ultraviolet radiation through a reducing atmosphere. As life has evolved, its symbiosis with the ocean has made it a phenomenon covering the Earth's surface, as discussed below.

The influence of the ocean on the behavior of the solid Earth is important as well. It has a major effect on the chemistry of the continental crust through the intermediacy of its sediments. The hydrosphere may be important to island arc volcanism by fluxing magmatic activity in subduction zones. Just how hydrated sediments influence this process of continent-building is not clear, and has been much debated for decades. In addition, the ocean may significantly influence the mechanical behavior of the lithosphere; a relatively small proportion of water can weaken rocks so they are more easily subducted.

The ocean is also the most pervasive connecting medium for global biogeochemical cycles. The magnitudes of most chemical reservoirs and their rates of accumulation are strongly controlled by the ocean, which is significantly older than the ocean basins beneath it.

It has become apparent that the atmosphere, oceans, and the hydrologic cycle cannot be considered in isolation, but rather as a more complete system that includes interactions between the biosphere, solid Earth, and perturbations caused by solar variability and orbital changes.

Reprinted from *Mission to Planet Earth* (Washington,.DC: National Academy Press, 1988) p 62-63, by permission of the publisher.

# The Greenhouse Effect

Earth's distance from the Sun has been influential in determining its climate. If Earth were much closer to the Sun, it might resemble Venus. Venus is described as a "hellish" place because the atmosphere filters out most of the visible spectrum of light but red. The second planet from the Sun, located between Mercury and Earth, Venus has an atmosphere that is 96 percent carbon dioxide ($CO_2$). Earth's atmosphere is only 0.035 percent $CO_2$. The $CO_2$ layer on Venus is so thick that it holds in almost all of the heat absorbed from the Sun, allowing little to escape—a phenomenon known as the **greenhouse effect**. As a result, the average temperature on Venus is 457° C, far too hot for any life, as we know it, to exist.

Earth exhibits a slight greenhouse effect too, but obviously not to the degree that Venus does. The greenhouse effect is life-sustaining, up to a point. Without it, the average temperature on Earth would be much lower, perhaps too cold for life to exist. At present, the greenhouse effect here is beneficial, but it may not always be so. The greenhouse effect on Earth is primarily due to water vapor in the atmosphere; however, carbon dioxide also contributes to the effect, and it is this greenhouse gas that is causing the greatest concern at present. Carbon dioxide is a byproduct of many things that we do, primarily the burning of fossil fuels—coal, oil, and gasoline. As more and more $CO_2$ is added to the atmosphere, the greenhouse effect increases, but it is unclear what the impact on climate will be because of many intervening factors.

Made of glass or translucent plastic, the climate-controlled greenhouse is perfect for nurseries to grow seedling plants and flowers. The glass walls and roof permit the plants to get the most sunlight possible. But the glass also traps heat in the greenhouse. "Greenhouse effect" is the name given to this phenomenon when substances, like glass, permit sunlight to pass through them but do not allow radiant heat to escape. Any time you have gotten into a car that has been sitting in the Sun with the windows rolled up, you have experienced the greenhouse effect.

The greenhouse effect exists because of the nature of light. Some forms of light are visible (like the colors in the rainbow) but others, like radiant heat (also called infrared radiation), are invisible. The greenhouse effect involves both visible and invisible light. The beginning of the process can be explained with a common example.

[redacted]

Paved roads can become extremely hot in the sunlight. Two different kinds of light come into play in heating the pavement. The light from the Sun strikes the pavement in the form of visible light. As the pavement absorbs this light, it heats up and then gives off heat. The temperature of the pavement will continue to rise until the amount of radiant heat (energy released to the environment as heat) given off is equal to the amount of energy absorbed from the sunlight. In direct sunlight, the resulting pavement temperature can be quite high, as anyone crossing an asphalt street barefoot on a summer day can testify.

The same principle operates in the greenhouse effect. The visible light from the Sun passes unimpeded through the glass of a greenhouse and strikes everything: the plants, the tables, the floor. These objects absorb the light and their temperatures increase. The objects then begin to radiate heat in the form of infrared light. However, the glass will not permit the infrared light (heat) to pass through it and escape, so all the heat stays trapped in the greenhouse.

Although carbon dioxide accounts for a tiny percentage of Earth's atmosphere (much less than one percent), it acts like the glass of a greenhouse—allowing sunlight to pass through and heat Earth, but partially preventing the resulting radiant heat from escaping out into space. Some of the radiant heat is reflected or absorbed by the $CO_2$ molecules, heating the lower atmosphere. Fortunately, the $CO_2$ content is not high enough to trap all of the infrared light, but since the start of the industrial revolution, more $CO_2$ is being produced every day as people burn coal, oil, and gas. Earth has natural processes that remove carbon dioxide from the atmosphere—photosynthesis and incorporation into ocean sediments—but they may not keep pace. We are in danger of warming up the planet and that presents serious consequences. Weather patterns could change and cropland could become unsuitable for farming. Melting polar ice caps could cause sea levels to rise and coastlines to flood.

These predictions are based on an assumption that global temperatures will increase. Logically, if the greenhouse effect increases, temperatures should rise globally; however, this global impact is yet to be clearly detected. One explanation is that temperatures are in fact not rising. Another is that measuring temperatures globally is a very difficult task, and erroneous temperature measurements may be incorrect in either direction. They may not indicate global warming that is actually occurring, or they may lead us to believe that temperatures are rising globally when in fact the increases are due to local phenomena such as densely populated areas. Another confounding factor is the fact that Earth goes through cycles of warming and cooling that are apparently unrelated to levels of carbon dioxide. Ice ages, for example, have been occuring every 100,000 years for millions of years, with less extreme ones at periods of 41,000; 23,000; and 19,000 years. The last ice age maximum was only 10,000 years ago.

Recently it was hypothesized that the oceans will serve as a kind of global thermostat to prevent air temperatures from rising above a certain temperature that is not too different from what we now experience. While scientists cannot agree on what the effect of increased atmospheric carbon dioxide will be, almost all agree that there will be some impact.

# Interaction of Human Activities with the Natural Environment

Human activities since the beginning of the industrial revolution have increased to such an extent that they must now be regarded as important factors in changing the environment. The effects are approaching a significant stage in altering the concentration of ozone and carbon dioxide in the atmosphere, in changing the surface properties by deforestation and erosion, and in other industrial and agricultural activities. Man is a major force now in the chemistry of the atmosphere and in the allocation of resources on land, and increasingly an influence on the ocean. Moreover, the influence can be subtle, as illustrated by the potential vulnerability of stratospheric ozone.

It has become apparent within the last decade that mankind has the ability to alter ozone, and to thus change the level of harmful ultraviolet radiation penetrating to the ground. We can do so by the direct injection of exhaust gases of high-flying aircraft into the stratosphere, by release of chlorinated gases used as aerosol propellants, as industrial solvents, as working fluids in refrigeration systems, and by complex perturbations to the global nitrogen cycle. These activities lead for the most part to reduction in ozone, but they are offset to some extent by thermal disturbances due to enhanced levels of carbon dioxide, causing a rise in ozone. Assessment of human impact is hampered by lack of understanding of the underlying physical, chemical, and biological influences regulating ozone in the natural state. This matter is critical because the gases responsible for change in ozone—the man-made chlorofluorocarbons and biologically formed nitrous oxide—have lifetimes ranging from 50 to 200 years. The self-cleansing function of the atmosphere proceeds slowly, therefore, and the effects of our actions today will persist for centuries into the future.

Carbon is the largest single waste product of modern society. We have added, by the burning of fossil fuel, over 100 billion tons of carbon to the atmosphere as carbon dioxide since the industrial revolution, with perhaps a quantity of similar magnitude transferred from the biosphere to the atmosphere over this same period as a consequence of land clearance for agriculture. The increase in the burden of atmospheric carbon dioxide is

SCILINKS.
THE WORLD'S A CLICK AWAY

**Topic: pollution**
**Go to: *www.scilinks.org***
**Code: PESA127**

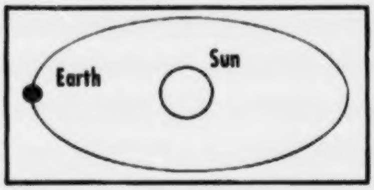
readily detectable. Approximately half of the carbon added to the system remains in the atmosphere and the remainder is presumed to have been taken up by the ocean on its way to the depths of the oceanic abyss, and eventual subduction into the Earth's interior. Attempts to model the process encounter difficulties, however, due in part to deficiencies in our knowledge of the nature of concurrent changes in the global biosphere, interactions with other nutrient cycles—nitrogen, phosphorus, and sulfur, for example—and lack of understanding of the processes of oceanic mixing. The time scales are such as to require a model for the atmosphere, ocean, and biosphere as a coupled system. The matter assumes some urgency since the rising level of carbon dioxide can lead to a change in climate, with associated change in the patterns of rainfall.

The ozone and carbon questions are but two examples of many global issues affecting the environment that must be faced in the years to come. Changes involving soil erosion, loss of soil organic matter, desertification, deforestation, overgrazing, diversion of freshwater resources, and increasing levels of air pollution and acid rain affect the physics, chemistry, and biology of the Earth.

Reprinted from *Mission to Planet Earth* (Washington, D.C.: National Academy Press, 1988) p 69-70, by permission of the publisher.

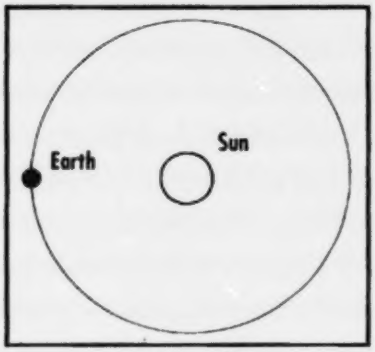
# Reason for the Seasons

The reason why Earth has four seasons—spring, summer, fall, winter—is often misunderstood. In part, this misunderstanding comes from diagrams similar to figure 1 where we try to give you a perspective on a nearly circular orbit as it would appear to a viewer almost in the plane of the orbit. From this perspective, the circular orbit looks elliptical. A similar perspective from directly above Earth's nearly circular orbit around the Sun looks like the diagram in figure 2. Having learned that Earth's orbit is actually an ellipse (although the ellipse is so round it is almost a circle), many people jump to the conclusion that diagrams like figure 1 represent the actual orbit around the Sun rather than a perspective view. This incorrect interpretation of the diagram then causes people to think that the planet is hotter in the summer because Earth is closer to the Sun than in the winter. Consider the following example. At the exact same time it is summer in the United States (the Northern Hemisphere), it is winter in Australia (the Southern Hemisphere). If Earth's distance from the Sun determines the seasons, then it should be the same season everywhere on the planet. In fact, Earth is actually farther away from the Sun during our (the Northern Hemisphere's) summer than it is during our winter.



(Not to scale)

**FIGURE 1**

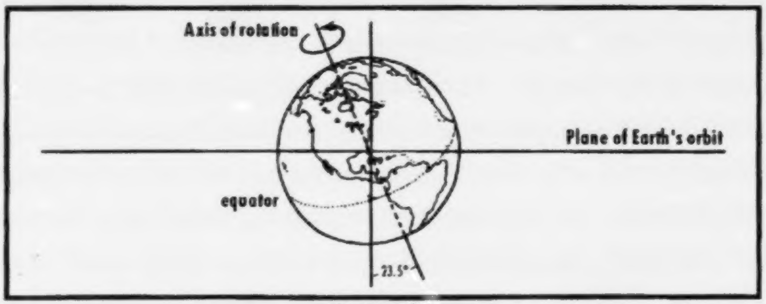


(Not to scale)

**FIGURE 2**

Earth's orbit around the Sun is more accurately represented by the circle drawn in figure 2. This slightly elliptical orbit does not account for the seasons, but another of Earth's characteristics of motion does.

Earth is spinning. When a ball spins, the line around which the ball turns is called the axis of rotation. Earth's axis of rotation is tilted in relation to the plane of Earth's orbit around the Sun. Figure 3 illustrates the difference. As Earth is spinning, it is also moving around the Sun. The position of Earth in its orbit around the Sun combined with the tilt of the axis of rotation then determines the season. Figures 4 and 5 show how the orbit and axis tilt work together. In the summer the Sun's rays are striking at as close to a 90° angle to the surface as is possible for that location.



(Not to scale)

**FIGURE 3**

Austin, TX is located at latitude 30° and Minneapolis,

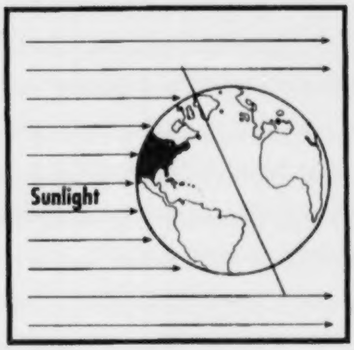


**FIGURE 4**
Summer in the Northern Hemisphere

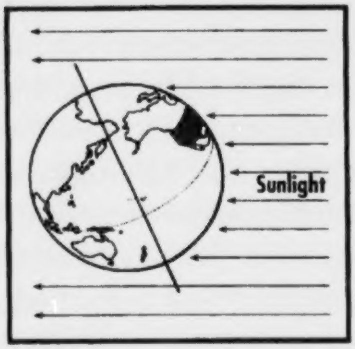


**FIGURE 5**
Winter in the Northern Hemisphere

MN is located at latitude 45°. On the longest day of the year, called the summer solstice, the Sun's rays strike Austin at 83.5° at noon and strike Minneapolis at 68.5°. During this time of year, the Sun's radiation is most intense. Figure 5 shows what happens six months later when Earth is on the other side of the Sun. On the shortest day of the year, the winter solstice, the Sun's rays strike Austin at an angle of 36.5° and strike Minneapolis at an angle of 21.5°. In this case, the Sun's rays are hitting the surface *at a greater slant* than they do during the summer, and the heating is not as efficient. It is not as efficient because the same amount of solar radiation is being spread out over a larger area. Compare figures 4 and 5. The second one represents our winter.

Figure 6 illustrates why perpendicular rays of light are more efficient at heating than slanting rays. In the picture at the top, the paper is standing vertically and the energy from the rays are concentrated in the small area ($A_1$). But when the paper is tilted back, notice that the same number of light rays, hence the same amount of energy, is now spread over a much larger area ($A_2$); therefore, it will not heat as fast.

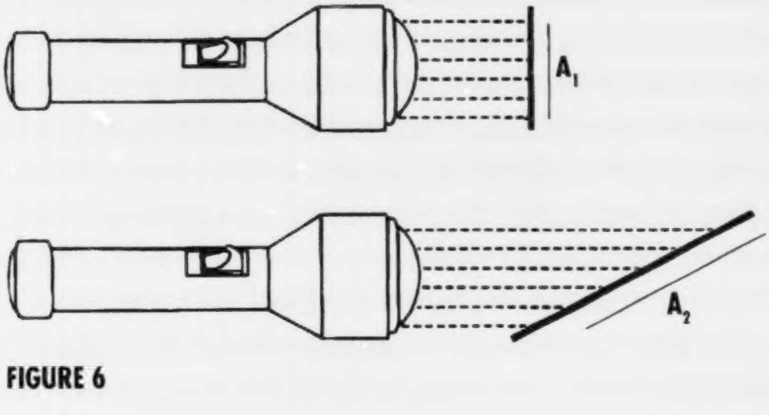


**FIGURE 6**

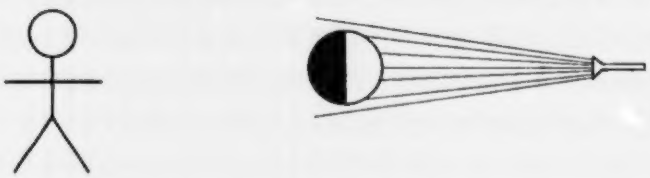
Similarly, when part of the surface of Earth is tilted with respect to the rays of sunlight, it will receive slanting solar rays and not heat as fast. Since Earth is round, some locations can be receiving direct sunlight while others receive it indirectly. This explains why it can be summer on one part of the planet and winter on another. In addition, because of the axis tilt, the days in summer are longer (allowing more time for solar heating) than in winter.

# Phases of the Moon

The Moon is the source of one of the most prevalent misconceptions in astronomy. The misconception is based on the belief that the Moon appears to change shape in a cyclical pattern every 29.5 days.

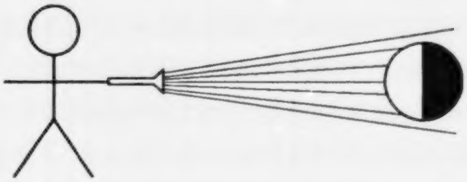
Throughout recorded history, people have been fascinated with the changing shape of the Moon. Every 29.5 days, the shape of the Moon predictably changes from a complete circle to a half circle to a crescent shape and then vanishes to rebuild again from a sliver of a crescent. Two common misconceptions attempt to explain the changing shape of the Moon. One is that clouds block our view of part of the Moon. The other is that the shadow of Earth falls on the Moon hiding different parts of it at different times. (The only time Earth's shadow falls on the Moon is during a lunar eclipse.)

**FIGURE 1** **New Moon**



In fact, the amount of the Moon that is illuminated is constant. We simply cannot see the entire illuminated portion all the time. When we can only see the shadowed ("dark") side of the Moon, it is referred to as the "new" Moon. To understand what is happening when we have a new Moon, imagine yourself in a totally dark room with a ball a couple of meters in front of you. In the dark you would not be able to see the ball. Now imagine that someone is standing in front of you on the other side of the ball and is shining a flashlight toward you. The light would shine on half the ball, but not the half you could see. You still would not be able to see the ball very well because the part facing you is shadowed (see figure 1). This is like the new Moon.

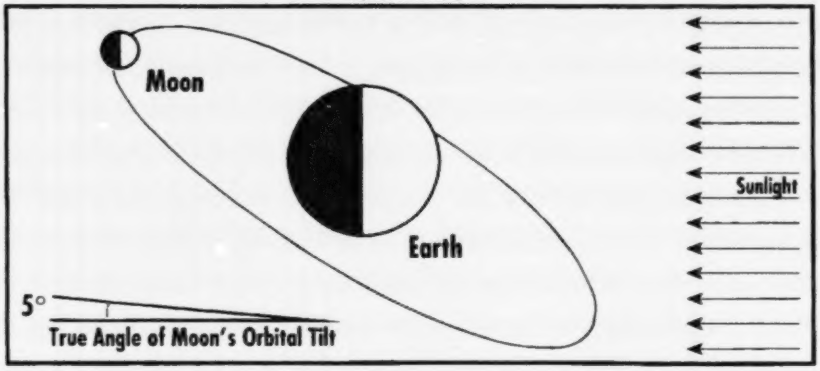
**FIGURE 2** **Full Moon**



Now if *you* were to hold the light and shine it toward the ball, you would see the half that is illuminated. This is like the full Moon (see figure 2). The illuminated part of the Moon as seen from Earth changes shape between a full moon and new moon because it is orbiting Earth. Figure 3 shows the positions of Earth and the Moon

**FIGURE 3** **The Tilted Plane of the Moon's Orbit**

**(Not to scale)**



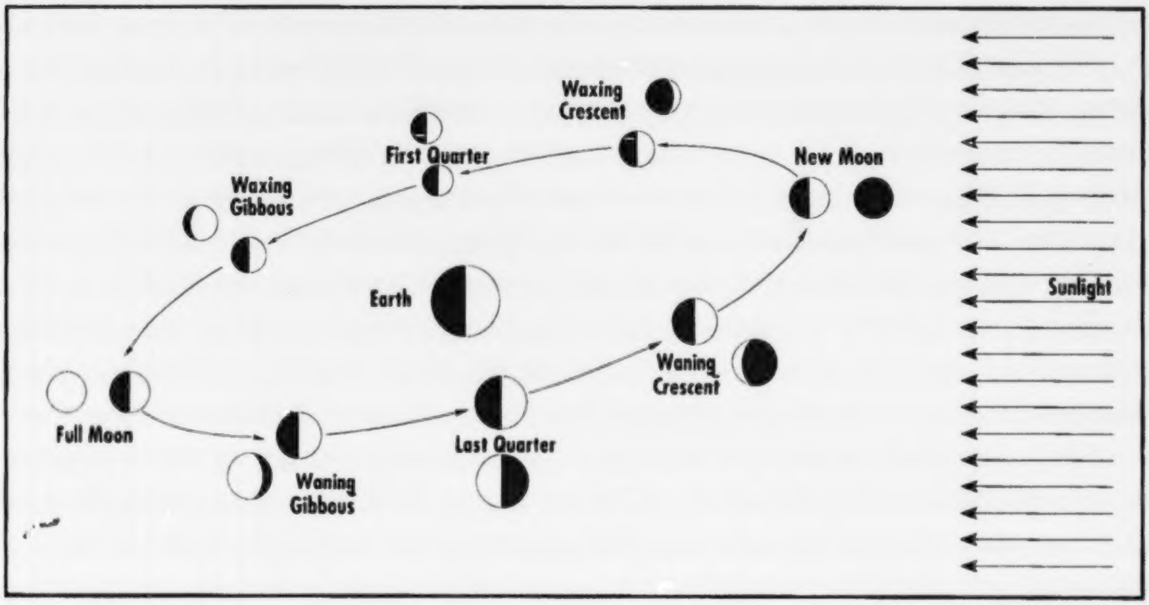
relative to the incoming sunlight when the Moon is seen as "full" from Earth. Notice that the Moon appears to be above Earth. This is because the orbital plane of the Moon around Earth is tilted with respect to the plane of Earth's orbit around the Sun. If this were not so, there would be a lunar eclipse each month instead of only occasionally.

The shape of the full Moon and the new Moon are easy to explain. The other shapes—crescent, half Moon, gibbous—are more difficult, but each one relates to the path the Moon travels around Earth each month. A model for how these intermediate shapes can be visualized is shown in figure 4. The inner ring of moons shows that half of the Moon is *always* illuminated. The outer ring shows what can actually be seen from Earth.

Earth and Pluto are the only planets in the Solar System with one moon. Mercury has none, and Mars has two. The other planets have many moons.

**FIGURE 4** **Phases of the Moon**

(Not to scale)



# Understanding the Moon Illusion

Over the years many of us undoubtedly have been fascinated by illusions, be they optical or slight of hand. Illusions are fascinating to everyone. One type of optical illusion that is worthy of note to astronomers is the type that employs background objects, lines, or other features to alter the appearance of foreground objects. For instance, two such illustrations are provided here for your amusement and befuddlement (figures 1 and 2). In both cases, straight lines tend to appear bent. If you don't believe that these lines are straight, turn the page on edge and peer down the lines. These are only a few of the many different illusions known.

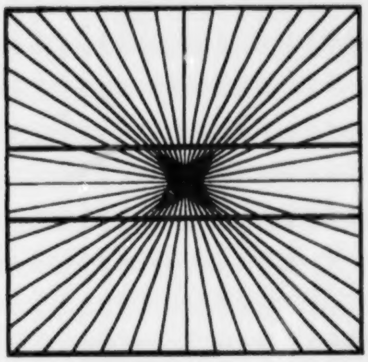


**FIGURE 1**

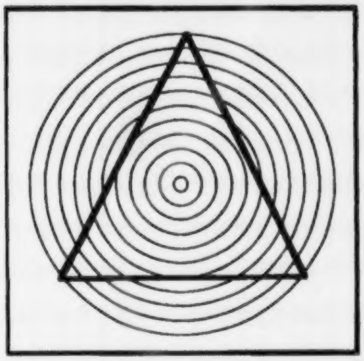


**FIGURE 2**

At times when the full moon is near the horizon it appears noticeably larger than when it is observed higher up in the sky. That this phenomenon is indeed an illusion can be shown by the measurement of the apparent angular size of the Moon under both circumstances. A ruler held at arm's length against the Moon while near the horizon and then higher up in the sky will reveal that the Moon has the same angular diameter. That the Moon's apparent size changes as a function of location is an illusion. This phenomenon is known as the "Moon Illusion."

Of all the attempts to explain the Moon Illusion, only one seems to adequately explain all the known variables. This solution deals with two seemingly divergent points. The first is one of the most memorable of illusions put forward and named after its originator, Mario Ponzo. The second deals with our perception of the sky.

The Ponzo Illusion, more commonly known as the "Railroad Track Illusion," is simply a set of "parallel" tracks that appear to converge in the distance due to perspective (figure 3). Two blocks of exactly the same size are inserted into the field of view. Just as in the preceding two examples, the background influences our perception of the foreground objects—the two blocks. The "nearer" of the two blocks appears smaller than its "more distant" companion. Why is this so?

Since the two blocks both exist in the plane of the paper, distance determination depends upon perspective and not parallax or any other suggestive clues. (We don't know how big the blocks "really" are.) Due to the convergence of the seemingly parallel lines, we accept the narrowing part of the picture as being farther away than the more widely separated portion of the tracks. Now, according to the intuitive brain, the top block is "farther away" than the bottom block. Since the "more distant" block appears the same angular size as the "closer" block, the brain accepts the "truth" that the more distant block is "really" much larger than the nearby block. This is clearly not the case to the analytical brain, and hence, the illusion. Simply put, the intuitive brain does not agree with the analytical brain.

You might wonder what the Ponzo Illusion has to do with the Moon Illusion. The connection seems quite tenuous until you consider how we perceive the sky. Perhaps you haven't noticed it, but the "distance" of the sky appears to be a function of where in the sky we direct our attention. The sky nearer the horizon appears much more distant than the point directly overhead. The perception probably results from observing such things as clouds in the daytime sky. The clouds overhead are nearer; those closer to the horizon are farther away. If the clouds are "supported" by the sky, then the sky too must have a similar characteristic. Suppose you had to estimate the size of the sky as it appears to you. Remembering the perception of the distances of clouds, you might say that it is 20 km to the horizon and substantially closer overhead, for example, 14 km. So a picture of this situation would resemble figure 4 with you, the observer, covered by the flattened hemisphere of the sky.

Since we are constantly, subconsciously, subjected to this perception of the sky, in all likelihood we carry it over into our perception of the nighttime sky. Figure 5 shows the nighttime case of this situation. It shows the path of the Moon as an observer would see it. When observing the full moon, in particular, we see it not as a spherical object, but as a flattened disc. Furthermore, this lunar disc appears to be embedded in the flattened

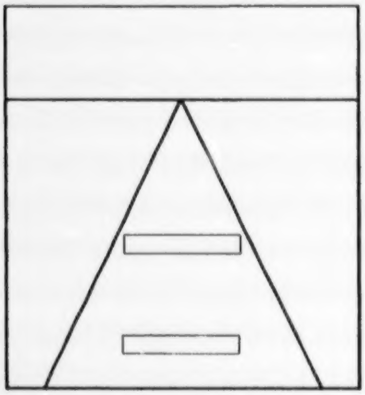
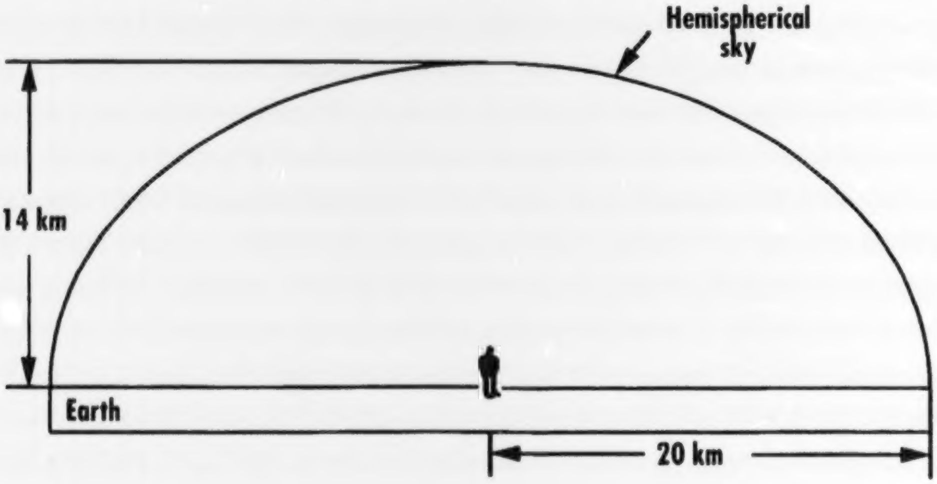


**FIGURE 3 Ponzo Illusion**

**FIGURE 4**



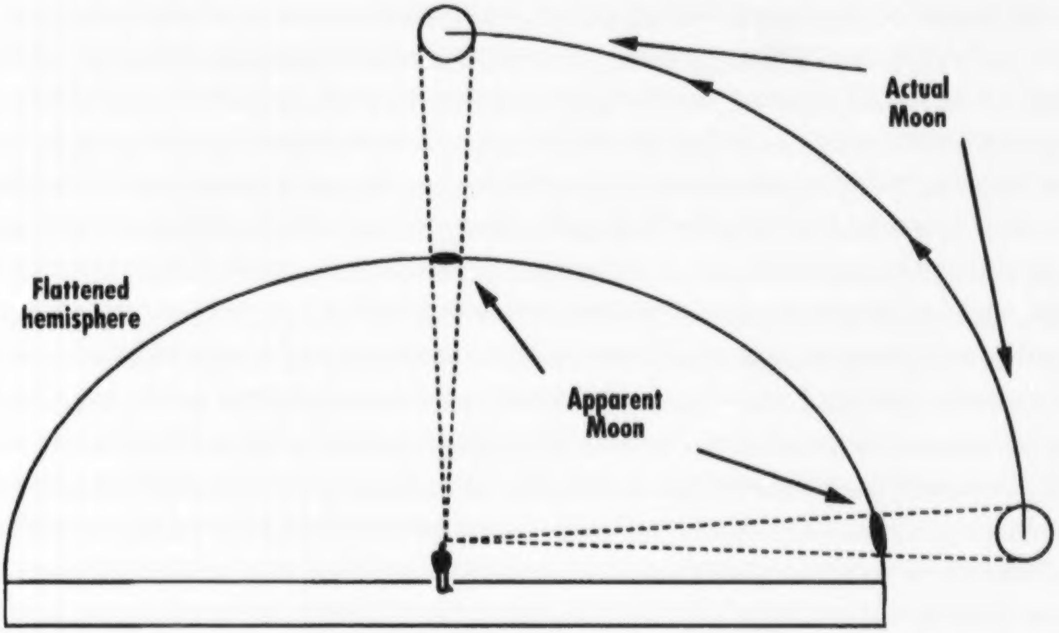
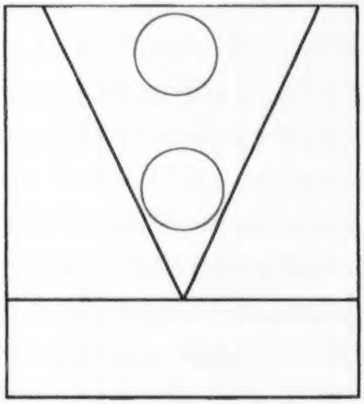


**FIGURE 5**

hemispherical surface of the sky. This figure shows how our preconceived notions concerning the sky lead us to conclude that the actual diameter of the lunar disc when close to the horizon is large, and considerably less so when higher up in the sky.

The similarities between the Moon Illusion and the Ponzo Illusion can now be examined. If backgrounds can influence our perception as to the size and nature of foreground objects, it is reasonable to assume that the sky affects the Moon in the same way the converging railroad tracks affect the two blocks of the Ponzo Illusion. If the Moon, like the blocks, has the same angular diameter anywhere in the sky, the apparent size of that body must be directly related to our preconceived notion that the horizon is farther from us than the point directly overhead. The explanation of the Moon Illusion is that it is nothing more than the Ponzo Illusion turned up side down (figure 6).

**FIGURE 6**



A few experiments will show that this is a reasonable explanation of the Moon Illusion mystery. It only stands to reason that if the background sky influences our perception of the Moon's size, then anything that "removes" this influence should cause the Moon Illusion to disappear. At the time of moonrise around the next full moon, look for the Moon positioned low along the eastern horizon. It is best to view the Moon from a brightly lit room and through a window dressed with sheer curtains. Draw the sheer curtains aside and look at the Moon. Note its apparent size. Now, pull the sheers across the window. When viewing the Moon through the sheers, the illusion of the Moon's great size disappears. It is through the curtain that you can see the brighter Moon, yet can no longer see the dimmer sky. Evidently, the background sky is part of the Moon Illusion.

An interesting experiment, working with afterimages impressed upon the eye by a bright light, can also show that this foreground/background explanation is correct. Almost everyone is familiar with afterimages. Some evening enter a dimly lit (not dark) room and stare at a bright, unshaded light bulb. Turn off the lamp and watch the afterimages form as you stare off into space. Several afterimages of the lamp will appear because of the almost imperceptible twitching of the eye during the observation of the lamp. All of these afterimages will be the same size by virtue of the fact that they were all produced by the same light bulb.

Note that the afterimages can be made to change size by "projecting" them onto a piece of paper and varying the eye-to-paper distance. As you move the paper toward your eyes, the size of the images shrink. When the paper is moved farther away, the images grow in size. Once again, it is the changing background that affects the perceived size of the observed image. A variation of this activity can be performed outdoors on a starlit night. After forming afterimages by staring at a bright light, project these images to different parts of the sky both high up and low down. You will achieve the same effect as in the darkened room using the piece of paper as your background.

In addition to explaining the Moon Illusion, these activities also explain why the Sun appears much larger when rising and setting. Everyone has seen the "giant" rising and setting sun, but few people seem to note that it too undergoes the same sort of illusory effect. Perhaps this is so because no one can bear to look at the Sun when it is high in the sky and shining brilliantly. The general impression is that the Sun is much larger in apparent size than the Moon. This is not so. The Moon and Sun have almost identical angular diameters. Similarly, our perceptions of the sky also influence our perception of the sizes of bright constellations. For instance, Orion the Hunter appears much larger when rising and setting than when higher up. Our perception of the sky as a "background" object really can affect the way we perceive the sizes of things in the sky and helps us understand the Moon Illusion.

By Carl J. Wenning, Director
Physics Department Planetarium
Illinois State University
Normal, Illinois 61761–6901

# Master Materials List

Originally conceived as a program in leadership development, the purpose of Project Earth Science was to prepare middle school teachers to lead workshops on topics in Earth science. These workshops were designed to help teachers convey the content of Earth science through the use of hands-on activities.

We suggest organizing *Project Earth Science: Astronomy* activities around three key concept areas, explained further in the Introduction on pages 11 and 12. To assist workshop leaders, this Master Materials List includes all of the equipment necessary for using the activities under each Concept Area.

## Concept Area I

**Activities:**

It's Only a Paper Moon
Time Traveler
Solar System Scale
Hello Out There!
How Far to the Star?

paper plates
metric rulers
index cards
scissors
a watch with second hand or stopwatch
a metric tape measure (30 meters or more)
a calculator (helpful but not necessary)
100 m of string
masking tape
flags (10 per group or student)
marking pens
a piece of candy or other treat per student
construction paper (or manila folder)
chalkboard or large piece of paper
chalk
tape (if manila folders are used)
a single hole punch

## Concept Area II

**Activities:**

Solar System Soup: The Formation of the Solar System
The Goldilocks Effect or "This Planet Is Just Right!"
The Greenhouse Effect
Creature Feature

a bag of vermiculite
containers of water
100 mL graduated cylinder
1000 mL beaker or buckets
stirring rods
a basin
Celsius thermometers
meter sticks
large disposable plastic cups

reflector lamps (with clamp) or gooseneck lamps with 75-watt bulb
a watch or clock
something to prop up thermometers
rubber bands
Celsius thermometers
a single hole punch
plastic wrap
a large bag of potting soil
graph paper
construction paper
scissors
glue
aluminum foil
straws
toothpicks
paper cups
transparent tape
floral wire

## Concept Area III

one or two globes
bright light source (a lamp with at least a 75-watt bulb)
an extension cord
Ping-Pong balls
cardboard
15-cm diameter Styrofoam ball
a pencil
black paint (suitable for Styrofoam)

**Activities:**

Reason for the Seasons
Ping-Pong Phases

# Resource Guide

## Curricula and Activities

Great Explorations in Math and Science (GEMS)
Lawrence Hall of Science
University of California-Berkeley
Berkeley, CA 94720-5200
Tel. 510-642-7771
e-mail: *www.lhs.berkeley.edu/gems*

Educational resources include *Earth, Moon, and Stars* (grades 5-8), *Moons of Jupiter* (Grades 4-8), *The Real Reasons for the Seasons* (grades 6-8).

PASS: Planetarium Activities for Student Success
Lawrence Hall of Science
University of California-Berkeley
Berkeley, CA 94720-5200
Tel. 510-643-5082
e-mail: *www.lhs.berkeley.edu/pass*

Twelve volumes for grades K-12 on astronomy and space science.

Project ASTRO
Astronomical Society of the Pacific
390 Ashton Avenue
San Francisco, CA 94112
800-335-2624
*custsvc@aspsky.org*

Publishes *The University at Your Fingertips: An Astronomy Activity and Resource Notebook* for grades 3-8+ .

Project STAR: The Universe in Your Hands
Kendall/Hunt Publishing Co.
4050 Westmark Drive
Dubuque, IA 52004
800-542-6657

Astronomy-based science course. Textbook and supporting materials. Produced by the Harvard-Smithsonian Center for Astrophysics (*cfa-www.Harvard.edu/cfa/sed*). Grades 9-12.

Project SPICA: A Teacher Resource to Enhance Astronomy Education
Kendall/Hunt Publishing Co.
4050 Westmark Drive
Dubuque, IA 52004
800-542-6657

A manual of 37 stand-alone astronomy activities. Sponsored by the Harvard-Smithsonian Center for Astrophysics (*cfa-www.Harvard.edu/cfa/sed*). Grades 2-12.

## Websites

Amazing Space (Space Telescope Science Institute)
*amazing-space.stsci.edu/*
Web-based K-12 activities.

American Astronomical Society, Education Office
*www.aas.org/education/index1.html*

Astronomical Society of the Pacific
*ww.aspsky.org/*
Slides, posters, books, other educational materials.

Astronomy Magazine
*www.astronomy.com/home.asp*

Astronomy Picture of the Day
*antwrp.gsfc.nasa.gov/apod/astropix.html*

Careers in Astronomy (from the American Astronomical Society)
*www.aas.org/education/career.html*
Spanish version: *www.aas.org/education/careersp.html*

CERES (Center for Educational Resources) Project (Montana State University)
*btc.montana.edu/ceres/*
Online library of K-12 astronomy resources.

Challenger Center for Space Science Education
*www.challenger.org*

Four Thousand Years of Women in Science
*crux.astr.ua.edu/4000WS.html*

Good Astronomy Activities on the World Wide Web (Astronomical Society of the Pacific)
*www.aspsky.org/education/astroacts.html*

Hands-On Astrophysics (American Association of Variable Star Observers)
*hoa.aavso.org/*

Hands-On Universe Project (Lawrence Hall of Science, University of California-Berkeley)
*hou.lbl.gov/*
A K-12 research and curriculum development program.

Hawaiian Astronomical Society
*www.hawastsoc.org/*
Uses many up-to-date NASA pictures to illustrate concepts in introductory astronomy.

Heavens Above
*www.heavens-above.com/*
Visible satellite passes and real-time orbit displays for any location in the world.

International Astronomical Union
*www.iau.org*

Mercury Magazine
*www.aspsky.org/mercury.html*

NASA for Kids
*www.nasa.gov/kids.html*
Astronomy updates and background information on space.

National Optical Astronomy Observatory (NOAO) Educational Outreach Program
*www.noao.edu/education/noaoeo.html*

Science Education Gateway (Space Sciences Laboratory, University of California-Berkeley)
*cse.ssl.Berkeley.edu/segwayed/about.html*
NASA scientists, science museums, and K-12 educators offer Earth and space science curricula via the World Wide Web.

The Space Place (Jet Propulsion Laboratory, Pasadena, CA)
*spaceplace.jpl.nasa.gov/moreinfo.htm*
Classroom activities, many for grades 9-12.

Sky and Telescope Magazine
*www.skypub.com/*

The Why Files (National Institute for Science Education)
*whyfiles.org/*
Explanations of the science behind the headlines.

## NASA Resources

The National Aeronautics and Space Administration (NASA) offers many educational resources for students and teachers on the subject of space. The 48-page booklet *How to Access Information on NASA's Education Program, Materials, and Services* is available at *education.nasa.gov* or through the NASA Field Centers' Educator Resource Centers, listed below. Contact the center listed for your state.

### NASA Education Websites

NASA Spacelink
*spacelink.nasa.gov/products/*
Locate all materials produced through the NASA Education Office

NASA's Central Operation of Resources for Educators (CORE)
*core.nasa.gov*
The national distribution center for NASA's audiovisual educational materials.

NASA's Space Science Enterprise
*spacescience.nasa.gov*

## NASA Field Centers' Educator Resource Centers

### Alaska, Northern California, Hawaii, Idaho, Montana, Nevada, Oregon, Utah, Washington, Wyoming

NASA Ames Research Center
NASA Educator Resource Center
Mail Stop 253-2
Moffett Field, CA 94035-1000
(650) 604-3574
*ccf.arc.nasa.gov/dx/basket/trc/trchome.html*

### Southern California, Arizona

NASA Dryden Flight Research Center
NASA Educator Resource Center
45108 North Third Street East
Lancaster, CA 93535
(661) 948-7347
*trc.dfrc.nasa.gov/Erc*

### California

NASA Jet Propulsion Laboratory
NASA Educator Resource Center
Village at Indian Hill
1460 East Holt Avenue, Suite 20
Pomona, CA 91767
(909) 397-4420
*learn.jpl.nasa.gov*

### Illinois, Indiana, Michigan, Minnesota, Ohio, Wisconsin

NASA Glenn Research Center
NASA Educator Resource Center
21000 Brookpark Road, MS 8-1
Cleveland, OH 44135
(216) 433-2017
*www.grc.nasa.gov/WWW/PAO/html/edteachr.htm*

**Connecticut, Delaware, District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont**

NASA Goddard Space Flight Center
NASA Educator Resource Center
Mail Code 130.3
Greenbelt, MD 20771
(301) 286-8570
*pao.gsfc.nasa.gov/gsfc/educ/trl/welcome.html*

**Virginia's and Maryland's Eastern Shores**

CSFC Wallops Flight Facility
NASA Educator Resource Center
Building J-17
Wallops Island, VA 23337
(757) 824-2298
*www.wff.nasa.gov/pages/educationoutreach.html*

**Colorado, Kansas, Nebraska, New Mexico, North Dakota, Oklahoma, South Dakota, Texas**

NASA Johnson Space Center
NASA Educator Resource Center
Space Center Houston
1601 NASA Road One
Houston, TX 77058
(281) 244-2129
*www.jsc.nasa.gov*

**Florida, Georgia, Puerto Rico, Virgin Islands**

NASA Kennedy Space Center
NASA Educator Resource Center
Mail Code ERC
Kennedy Space Center, FL 32899
(321) 867-4090
*www.ksc.nasa.gov*

BEST COPY AVAILABLE

**Kentucky, North Carolina, South Carolina, Virginia, West Virginia**

NASA Langley Research Center
NASA Educator Resource Center
Virginia Air and Space Center
600 Settlers Landing Road
Hampton, VA 23669-4033
(757) 727-0900, ext. 757
*www.vasc.org/erc/*

**Alabama, Arkansas, Iowa, Louisiana, Missouri, Tennessee**

NASA Marshall Space Flight Center
NASA Educator Resource Center
U.S. Space and Rocket Center
One Tranquility Base Drive
Huntsville, AL 35758
(256) 544-5812
*www.msfc.nasa.gov/education/erc*

**Mississippi**

NASA Stennis Space Center
NASA Educator Resource Center
Building 1200
Stennis Space Center, MS 39529-6000
(228) 688-3220
*education.ssc.nasa.gov/htmls/trc/trc.htm*

| Activity # | Subject Matter and Content | Scientific Inquiry | Unifying Concepts and Processes |
|---|---|---|---|
| **Activity 1** | Indirect measurement | How do we measure distance? | Evidence and models |
| **Activity 2** | Concept of light year as unit of distance | How do we express very large distances? | Applying existing knowledge to new situations |
| **Activity 3** | A scale model of distance | What is Earth's place in in the Solar System? | Evidence and models |
| **Activity 4** | Light has a finite speed | What are the consequences of light having a finite speed? | Evidence and models |
| **Activity 5** | Parallax (indirect measurement) | How do we measure distance? | Relationship between explanation and evidence |
| **Activity 6** | Solar System accretion | What is accretion? | Evidence and models |
| **Activity 7** | Distance and light | What factors make it possible for life to exist on a planet? | Interactions between concepts within a system |
| **Activity 8** | Nature and behavior of light | What are relationships between concepts within a system? | Relationship between explanation and evidence |
| **Activity 9** | Compare Venus and Mercury | Why are Venus and Mercury unable to support life as we know it? | Interactions between concepts within a system |
| **Activity 10** | Earth's seasons | What causes Earth's seasons? | Interactions between concepts within a system |
| **Activity11** | Moon's phases | What causes phases of the Moon? | Interactions between concepts within a system |

| Technology | Personal/Social Perspectives | Historical Context | **Activity Name** |
|---|---|---|---|
| Technology of measuring devices | | Cross staffs used by ancient peoples for navigation | **It's Only a Paper Moon** |
| | | | **Time Traveler** |
| | | Copernicus discovered relative distances within Solar System | **Solar System Scale** |
| Electromagnetic radiation of different wavelengths received by various telescopes/instruments | | | **Hello Out There!** |
| Technology of measuring devices | | Parallax predicted by ancient Greeks | **How Far to the Star?** |
| | | | **Solar System Soup: The Formation of the Solar System** |
| Measuring temperatures and distances | | | **The Goldilocks Effect or "This Planet Is Just Right!"** |
| | Greenhouse effect | | **The Greenhouse Effect** |
| | Greenhouse effect | | **Creature Feature** |
| | | | **Reason for the Seasons** |
| | | | **Ping-Pong Phases** |

# SCILINKS®

THE WORLD'S A CLICK AWAY

*Project Earth Science: Astronomy* brings you *sci*LINKS, a new project that blends the two main delivery systems for curriculum—books and telecommunications—into a dynamic new educational tool for children, their parents, and their teachers. *sci*LINKS links specific science content with instructionally rich Internet resources. *sci*LINKS represents an enormous opportunity to create new pathways for learners, new opportunities for professional growth among teachers, and new modes of engagement for parents.

In this *sci*LINKed text, you will find an icon near several of the concepts you are studying. Under it, you will find the *sci*LINKS URL (*www.scilinks.org*) and a code. Go to the *sci*LINKS website, sign in, type the code from your text, and you will receive a list of URLs that are selected by science educators. Sites are chosen for accurate and age-appropriate content and good pedagogy. The underlying database changes constantly, eliminating dead or revised sites or simply replacing them with better selections. *sci*LINKS also ensures that the online content teachers count on remains available for the life of this text. The *sci*LINKS search team regularly reviews the materials to which this text points—revising the URLs as needed or replacing webpages that have disappeared with new pages. When you send your students to *sci*LINKS to use a code from this text, you can always count on good content being available.

The selection process involves four review stages:

1 A cadre of undergraduate science education majors searches the World Wide Web for interesting science resources. The undergraduates submit about 500 sites a week for consideration.

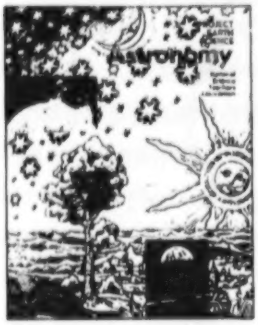
2 Packets of these webpages are organized and sent to teacher-webwatchers with expertise in given fields and grade levels. The teacher-webwatchers can also submit webpages that they have found on their own. The teachers pick the jewels from this selection and correlate them to the *National Science Education Standards*. These pages are submitted to the *sci*LINKS database.

3 Scientists review these correlated sites for accuracy.

4 NSTA staff approve the webpages and edit the information for accuracy and consistent style.

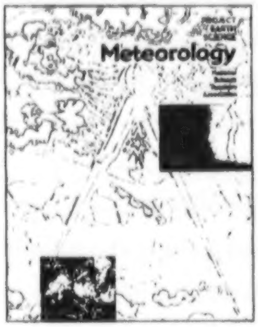
*sci*LINKS is a free service for textbook and supplemental resource users, but obviously someone must pay for it. Participating publishers pay a fee to NSTA for each book that contains *sci*LINKS. The program is also supported by a grant from the National Aeronautics and Space Administration (NASA).

# the Project Earth Science series



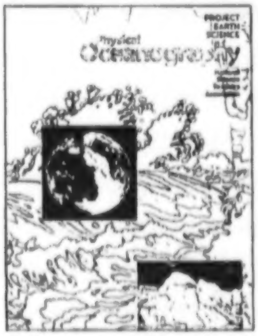
## Astronomy

The hands-on, teacher-tested activities in *Astronomy* bring the sometimes daunting concepts of astronomy down to Earth. Background information, supplementary readings, and suggestions for integrating other disciplines provide a framework for launching a successful introduction to astronomy. Students will discover Earth's uniqueness by examining it as a part of the whole Solar System. How did the planets form? Are we seeing a star's present or past? *Astronomy* will lead you and your students on an exploration that takes you to the stars and back.
Grades 5–10, 2001 revised edition, 160 pp. #PB090X



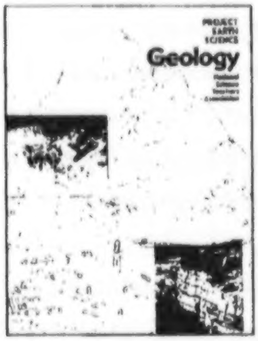
## Meteorology

*Meteorology* brings the atmosphere into your classroom, with 19 hands-on activities, 10 supplemental readings, and a thorough resources guide. Learn to read weather maps and do forecasts; model the water cycle on a tabletop; and use real data to track Hurricane Andrew as it moves over ocean and land. Other activities explain why the equator heats more quickly than the poles and why dust is needed for cloud formation. Supplemental readings provide educators with the detail they need to feel comfortable with each topic.
Grades 5–10, 1999 revised edition, 240 pp. #PB103X



## Physical Oceanography

Water is found in such abundance on Earth that most of us don't realize how unique it is. *Physical Oceanography* will lead you and your students on a mission of discovery from water's molecular structure to its gravitational dance with the Moon. Explore the effects of salinity and density in ocean water. Simulate the effects of oil spills and other ocean pollutants. Find out why water is known as the "universal solvent." It's all here—teacher-tested and beautifully presented—everything you need to understand how special water is.
Grades 5–10, 2000 revised edition, 212 pp. #PB114X



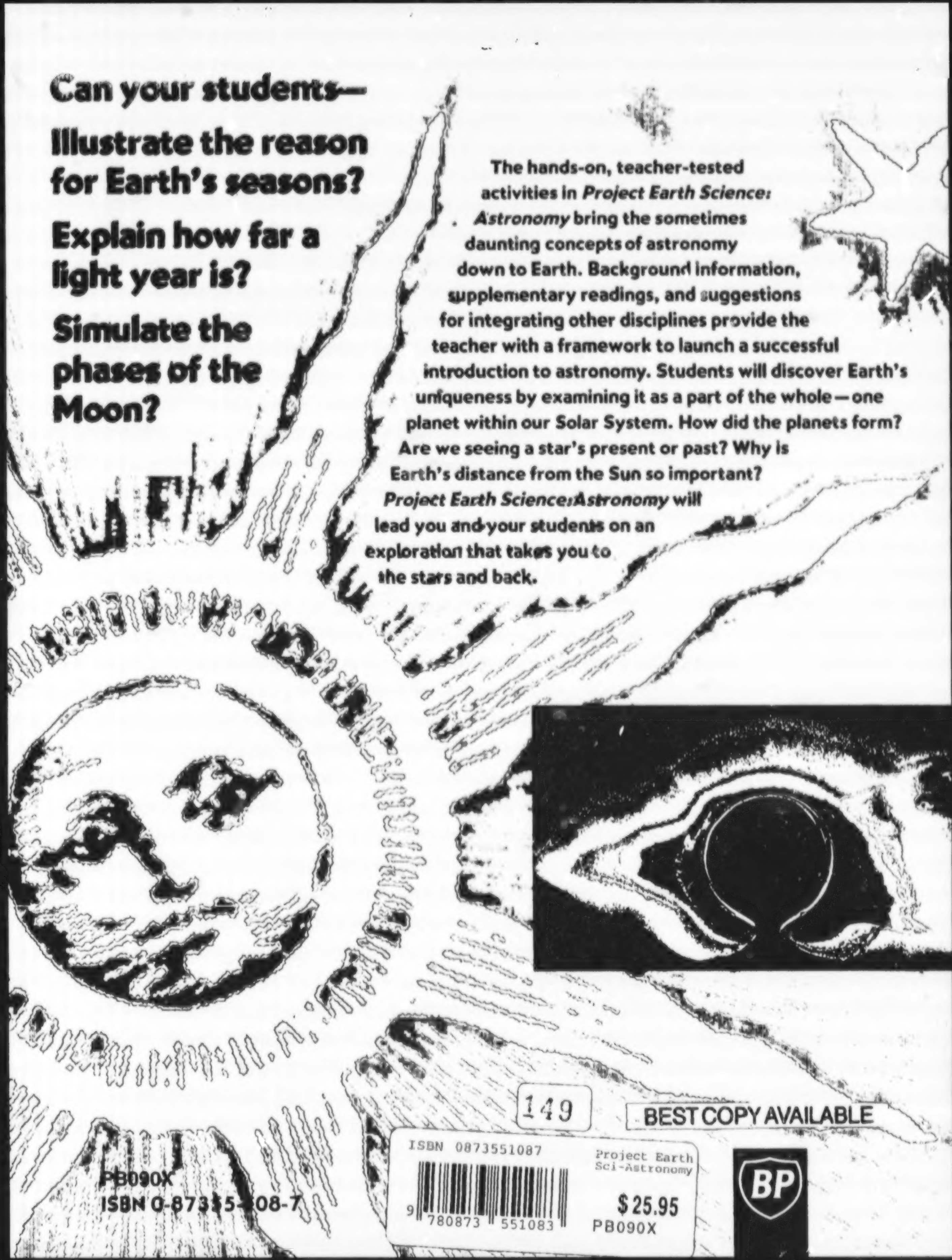
## Geology

Explore the way the Earth is built with these activities on plate tectonics, volcanism, the rock cycle, and more. *Geology* includes careful discussions on the uses and limitations of popular models used to explore these larger-than-the-classroom subjects. Supplemental readings cover recent research on plate tectonics, volcanoes, and earthquakes.
Grades 5–10, 2001 revised edition, 216 pp. #PB111X

BEST COPY AVAILABLE

**To order, or for a free catalog, call: 1-800-277-5300, or visit http://www.nsta.org/store**

**National Science Teachers Association**



**Can your students—**

**Illustrate the reason for Earth's seasons?**

**Explain how far a light year is?**

**Simulate the phases of the Moon?**

The hands-on, teacher-tested activities in *Project Earth Science: Astronomy* bring the sometimes daunting concepts of astronomy down to Earth. Background information, supplementary readings, and suggestions for integrating other disciplines provide the teacher with a framework to launch a successful introduction to astronomy. Students will discover Earth's uniqueness by examining it as a part of the whole—one planet within our Solar System. How did the planets form? Are we seeing a star's present or past? Why is Earth's distance from the Sun so important? *Project Earth Science: Astronomy* will lead you and your students on an exploration that takes you to the stars and back.

BEST COPY AVAILABLE

PB090X
ISBN 0-87355-108-7

ISBN 0873551087
Project Earth
Sci-Astronomy
9 780873 551083
$ 25.95
PB090X

**U.S. Department of Education**
*Office of Educational Research and Improvement (OERI)*
*National Library of Education (NLE)*
*Educational Resources Information Center (ERIC)*

ERIC®

# NOTICE

# Reproduction Basis

☑ This document is covered by a signed "Reproduction Release (Blanket)" form (on file within the ERIC system), encompassing all or classes of documents from its source organization and, therefore, does not require a "Specific Document" Release form.

☐ This document is Federally-funded, or carries its own permission to reproduce, or is otherwise in the public domain and, therefore, may be reproduced by ERIC without a signed Reproduction Release form (either "Specific Document" or "Blanket").

EFF-089 (3/2000)